INTERRELATIONS OF THE FOSSIL FUELS.*

IV.

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(*Read March 5, 1920.*)

The Paleozoic Coals.

In a great part of the areas, where deposits of Permo-Carboniferous age are exposed, the passage from Triassic is gradual; at most, the plane of contact shows only petty discordance of stratification. But in many extensive areas, the succession is incomplete and one or more members are missing, so that the Triassic may rest on any formation from Archean to Permian. In like manner, where the succession is complete, the Permian may pass downward into the distinctly Carboniferous so gradually that no definite boundary can be determined stratigraphically or by aid of changes in plant or animal life. At times, deposits assigned to the Permian rest on pre-Carboniferous rocks; at others, there is distinct discordance between Permian and Carboniferous, while in vast areas the succession is apparently conformable throughout. Lithological changes usually occur in the upper part of the section; at one time, the presence of red rocks was considered proof that Permian had been reached. This opinion is not final, in many regions red beds occur in distinctly Carboniferous deposits. Frequently, the basal portion of the Permian contains conglomerates, holding pebbles, striated seemingly by glacial action.

The problem of the relations between Permian and Carboniferous coal measures is vexatious to the last degree, as the testimony of stratigraphy, paleontology and paleobotany seems to be in conflict. In some cases, the conflict is not real, but in others it is a

* Part I appeared in these *Proceedings,* Vol. LV., pp. 21–203; Part II. in Vol. LVI., pp. 53–151; Part III. in Vol. LVII., pp. 1–48.

PROC. AMER. PHIL. SOC., VOL. LIX, Z, DEC. 20, 1920.

fact and it can be removed only by revision of conceptions, which have become laws, because accepted for a long time. But questions of nomenclature and relations have only incidental importance in connection with matters under consideration in this work. The term Permo-Carboniferous will be employed here, as it has been accepted by many students; it renders unnecessary all discussion as to propriety of regarding the Permian as more than a subordinate division of the Carboniferous.

Permo-Carboniferous Coals.

Australia.

Queensland.—Jack and Etheridge[1] include under the name Permo-Carboniferous, the rocks between Devonian and Trias-Jura and divide them into the Star, Gympic and Bowen formations.

The Star and Gympic yield a flora of distinctly Carboniferous type; the fauna is marine and certainly allied to that of the Lower Carboniferous. The relations of these formations to each other were not determined, as they occur in isolated areas; they have *Calamites, Lepidodendron, Cordaites* and eleven genera of invertebrates in common, but a number of species are peculiar to the Star. *Lepidodendron* abounds in sandstones and some shales. The Gympic beds are much disturbed, those of the Star, very little.

The Bowen, divided by Jack into Lower, Middle and Upper, had not been found in contact with the Lower Carboniferous up to the time when the report was prepared. Lycopodiaceous plants are wanting, their place being taken, apparently, by the fern *Glossopteris.* The Lower Bowen has yielded no remains of animals and it is capped by a series of bedded volcanic rocks; the Middle is rich in mostly marine mollusks and contains some remains of land plants; The Upper had abundance of land plants and one bed has marine mollusks like those of the Middle. The Bowen is thought by Jack to be equivalent to the upper portion of the New South Wales Permo-Carboniferous.

The Lower Bowen, consisting of grits, sandstones, conglomerates

[1] R. L. Jack and R. Etheridge, Jr., "The Geology and Palæontology of Queensland, etc.," Brisbane, 1892, pp. 3, 70, 135, 141, 147–159, 161–171.

and shales, contains remains of reed-like plants with fragments of silicified wood in the sandstones and shales; black shale with highly carbonaceous bands was seen at one locality, but no coal was discovered anywhere. The Middle or marine Bowen, composed of yellow to gray sandstone, with blue to yellow-gray shales and some ferruginous bands, is remarkably rich in mollusks, some of which belong to Permian types. Vertical rootlets in shales and sandstones are taken by Jack to indicate occasional recurrence of land surfaces. Silicified trunks of trees, prostrate, were seen in sandstone at several localities. Only two coal seams were recognized; the Kennedy, of merely local importance, is about 2 feet thick, double or triple, and rests on a floor containing vertical rootlets; the Garrick, higher in the formation, and 4 feet 9 inches thick, shows near the bottom a light lustrous coal in nodules of 3 to 4 inches diameter. The coal in the main portion of the seam yields a bright, hard coke but coke from the nodules is spongy. The floor is soft sandstone and contains rootlets; the prevailing plants are *Sphenopteris* and *Glossopteris*. The Upper Bowen, including many sheets and dikes of diorite, consists of gray shales and greenish-gray sandstones with some conglomerate. The Daintree coal seam, near base of the formation, is exposed in the bed of Bowen River, where it is less than 10 feet below a mass of diorite. The section is (1) Burnt coal, partly columnar, contains *Glossopteris*, 3 feet 7 inches; (2) black shale, 1 inch; (3) burnt coal, 3 inches; (4) stony burnt coal with silky plant débris, 6 inches; (5) light, porous, crumbling coal, with concretionary nodules of better coal, 8 inches; (6) blue-black shale, 2 feet 3 inches; (7) light brownish-black, laminated coal, with laminae of oil-shale, 7 feet; (8) blue-black shale, 2 feet 3 inches; (9) good coal, 3 inches; total, 17 feet 5 inches. The influence of the diorite sheet disappears at about 15 feet. The McArthur seam, higher in the section, is in 5 benches with a total thickness of 12 feet 3 inches, but the coal is only 5 feet and has 32 per cent. of ash. The sandstones above this coal contain large stems of drifted coniferous trees, which are silicified and, at times, retain some of their roots. A third seam, unimportant, is near the top of the formation and only a few feet below red sandstone with a marine fauna.

The Bowen coals are inferior; those of the Middle have from 11

to almost 17 per cent. of ash, while those from the Upper have from 14 to 38. Great variation occurs in a single seam; anthracite at one place, 4 feet 4 inches thick, has at one mine only 3.5 per cent. of ash, whereas in another it has 23.61. No igneous rocks were seen in the neighborhood.

New South Wales.—The Permo-Carboniferous, according to David,[2] is divisible within the Hunter River region into

The Newcastle Series, freshwater, with coal seams.......	1,400 to 1,500 feet
The Dempsey Series, freshwater, no workable coal......	200 to 2,000 feet
The Tomago Series, with coal seams......................	1,600 to 1,800 feet
The Upper Marine Series, without coal..................	5,000 to 6,400 feet
The Greta Series, with coal seams......................	150 to 300 feet
The Lower Marine Series, with little coal..............	4,800 feet

A great gap exists between Carboniferous or "Gympic" deposits, which, most probably, belong to the Lower Carboniferous. On the border of Queensland, in the Ashland coal field, the Permo-Carboniferous rests in great unconformity against the Lower Carboniferous, which is not far from 20,000 feet thick. This vast mass consists, in the lower and middle divisions, of marine beds, but the upper division is mostly lava and volcanic tuffs. The gap is indicated not only by the angular unconformity but also by the fact that but one genus of plants is common and the contrast in fauna is almost as great.

The Lower Marine Series has, at base, a deposit about 200 feet thick, underlying a basalt sheet and containing many glaciated pebbles. The first appearance of *Gangamopteris* is at about 3,000 feet from the base; and at 500 feet higher is a coal seam of rather inferior quality, 10 feet 6 inches thick, inclusive of the partings which contain *Gangamopteris*. The Greta Series, sandstones and shale, has near the base the Homeville seam, 3 to 11 feet 6 inches thick, hard, bituminous coal; at the South Greta mine it rests on Kerosene shale. At 50 feet higher, the interval being filled with sandstone, conglomerate and shale, is the Greta seam, 14 to 32 feet thick, with floor of shale and roof of sandstone or conglomerate. Where the

[2] T. W. E. David, "The Geology of the Hunter River Coal Measures, New South Wales," *Mem. Geol. Survey of New South Wales,* No. 4, 1907, pp. 311–327, 354.

roof is sandstone, marine fossils are present at a little way above the coal. Locally, owing to increase of the alga, *Reinschia australis,* it passes over to cannel or even to Kerosene shale. The coal seams of this series divide toward the north, which David takes to be wholly normal; the Carboniferous had been elevated to form highlands on that side, so that the quantity of transported material increased in that direction. The Tomago Series, sandstones, conglomerates and coal seams with beds of iron ore, has six workable seams, which yield excellent coal but too friable for shipment, being inferior in that respect to coal from the Greta and Newcastle. The Newcastle Series has many coal seams of high grade and great persistence. This series is notable because of abounding *Vertebraria* in the floor and of *in situ* tree-stems in the roof of coal seams.

Wilkinson,[3] many years ago, separated the deposits into Upper and Lower Carboniferous. The latter has marine fossils in many beds, while in others *Lepidodendron, Sigillaria* and *Calamites* abound, but workable coal seams are unknown. This is equivalent to the Lower Marine Series of the Hunter River field. The Upper Carboniferous has, below, the important seams at Greta and East Maitland, separating the two Marine Series. The plants are species of *Glossopteris, Phyllotheca, Noeggerathia* and *Annularia. Phyllotheca* and *Glossopteris* occur on slabs, associated with characteristic fossils, which McCoy, de Konninck and others have recognized as Carboniferous. The Upper Carboniferous had been referred to the Permian, but Wilkinson accepted this as only a provisional reference. The characteristic plants are *Glossopteris, Gangamopteris, Vertebraria, Phyllotheca* and *Sphenopteris,* but marine shells appear to be wanting. This upper division is evidently equivalent to David's Tomago, Dempsey and Newcastle. The *Glossopteris* of New South Wales is of interest because of the memorable controversy between McCoy and Clarke,[4] in which the former maintained that the presence of this plant proved Mesozoic age for the deposits, because in India it occurs in Oolitic rocks, whereas the

[3] C. S. Wilkinson, "Notes on the Geology of New South Wales," Sydney, 1882, pp. 44, 45, 51.

[4] W. B. Clarke, "Remarks on the Sedimentary Formations of New South Wales," in Mines and Min. Statistics of New South Wales, 1875, contains a history of this dispute, pp. 161 et seq.

former asserted that the fauna was absolute proof of Paleozoic age. It may be well to recall that this fauna reappears in Queensland at top of the Bowen formation.

According to Mackenzie,[5] the coal seams of the upper measures are much broken by partings, usually thin. The seams, at times, are thick, 8 to 26 feet, but much of the coal is poor. A faux-toit, consisting of coarse coal and "coal and bands," 4 to 12 feet thick, is present at many localities. The benches frequently differ in character of the coal. The roof and floor are usually shaly clay and in most cases the roof is plant-bearing. The coal seams of the lower coal group are much divided and show great difference in the several benches. Occasionally the underclay is crowded with *Vertebraria*.

The lens shape of coal seams is a by no means rare feature. The important seam at Greta suffices for illustration.[6] At the Greta mine, it has 6 benches, including one of Kerosene shale, and is 26 feet thick, inclusive of 6 feet of partings and inferior coal; but within 32 chains it becomes only 17 feet 6 inches, while at three miles north it is but 7 feet 6 inches and the Kerosene shale is wanting. That shale occurs as lenticular deposits with the seams, and bears close resemblance to cannel in mode of occurrence. Liversidge[7] states that at Joadja Creek this mineral contains *Glossopteris* and *Vertebraria*. The fronds of the former usually are spread between the laminæ but the latter crosses them.

David[8] says that the Stony Creek and Greta coal measures, underlying the Upper Marine Series, are thin at the south but become thicker northward, the increase being due to splitting of an important coal seam into several thinner ones. At East Maitland, he saw in the East Maitland (Tomago) series a coal seam, consisting of an upper division, clays and coal, 4 feet, and a lower division, coal and thin partings, 4 feet. At little way northward, the divisions have become distinctly separate seams and, at another locality farther north, the interval between them is 140 feet. In a later report, he

[5] J. Mackenzie, "Mines and Mineral Statistics," pp. 209–243.

[6] Annual Rep. Department of Mines, 1883, p. 149.

[7] A Liversidge, "Description of the Minerals of New South Wales," Sydney, 1882, p. 160.

[8] T. W. E. David, Ann. Rept. Dept. of Mines for 1887, pp. 147, 149, 151; the same for 1890, p. 229.

notes his discovery of *Glossopteris* leaves in closely matted layers within a soft fireclay. They were undecomposed, were not brittle or carbonized, but retained the original substance. Soaked in glycerine and water, they could be unrolled and laid out flat. A large number of the specimens were mounted and placed on exhibition in the Museum of the Department of Mines.

More than forty years ago, Wilkinson stated that "on the coast, near the Nobby, Newcastle, may be seen several trunks of trees up to one foot thick, with roots attached, starting from a seam of coal and embedded in the strata in the upright position in which they grew." In the interval since Wilkinson studied the region, detailed examinations have been made and the conditions have been presented by David[9] in his remarkable memoir on the Hunter River. It will suffice here to cite only the description of features observed in the Newcastle or highest Series. That contains 12 seams, which are workable in more or less extensive areas and occur in two divisions, separated by a thick deposit containing much diagonally-bedded conglomerate in great lenses. The color of this mass is greenish- to reddish-brown.

The Wallarat or Bulli seam, at top of the Permo-Carboniferous, directly underlies the Trias and is much eroded; its underclay is a root-bed. The Great Northern seam, 14 feet thick and 120 feet lower, underlies conglomerate and is much eroded at the junction. The conglomerate, at base, holds flattened stems of trees. At the cliffs of Catherine Hill Bay, the top of this seam has numerous stumps of large trees and the underclay has vertical *Vertebraria*, separated by intervals of about 2 feet Below the floor of this coal seam is the Fennel Bay fossil forest, which is persistent in the Newcastle Series at 20 to 80 and 100 feet below the Great Northern. These plants are *in situ*. At somewhat more than 200 feet below the Great Northern the lower Pilot seam is reached, 5 feet thick and 33 feet below the upper Pilot, the interval being filled with tufaceous beds. The top portion of the lower seam, splint coal, has great numbers of vertical trunks and stumps, rooted in the coal, in some cases 30 feet high, reaching to the floor of the upper bed.

[9] T. W. E. David, "Geology of the Hunter River Coal Measures," pp. 3–41, 330–332.

This upper bench of the lower Pilot is a network of long straight roots radiating from the stumps. David recognizes that the tuffs must have accumulated rapidly as, otherwise, the stems would have rotted away. This roof forest is well shown on French Bay of Lake Macquarie. The tree stems are chalcedony above the coal, but in the coal they are a hydrocarbon. They are 10 to 15 inches thick and are about 5 yards apart. Drops of resinous matter, distilled from the broken branches, are present in tuff surrounding the stems, such as one finds in recent tuffs within the Andes region. The lower bench of the bed has numerous stems and vertical roots, which David conceives may be the remains of another fossil forest. The under clays of both Pilot seams have abundant *Vertebraria,* while some partings have *Vertebraria* and *Sporangia.*

The Burwood seam, 13 feet thick inclusive of partings, gives evidence of contemporaneous erosion before or during deposition of the overlying shale. The conglomerate above has rounded pebbles of coal, one to three inches diameter. David is inclined to believe that these came from the Burwood seam, though he grants that the source may have been one of the Greta seams. They are proof that when the conglomerate was deposited coal, already hard, existed. *Vertebraria* abounds in underclays of coals in the lower division and stumps, *in situ,* were seen in the roof of several seams. A gravel bank, 70 feet thick and one fourth to one half mile wide, marks the course of an ancient erosion. The vertical stems, in all cases, are conifers.

In summing up the facts, David state that the floor of each seam contains abundance of *Vertebraria* (the root of *Glossopteris*), while the roof shows more or less well preserved stumps of *in situ* trees. The lower part of stumps and roots, where they form part of the coal seam, still retain a large proportion of the original carbon and only the upper part has become slightly silicified. But the tree stump, where extending a few feet above the coal seam, is completely silicified, changed into chalcedony, but the minute tissue is usually preserved. Where the woody portions are replaced with carbonate of iron, retaining the woody structure, the bark, one or two inches thick, has become brittle, bright bituminous coal. This leads him to suggest that the bright laminæ of the coal were made

from bark of coniferous trees and that the dull, splinty laminæ, containing a notable proportion of mineral charcoal, were derived from *Glossopteris* stems and leaves. Sporangia abound but not in quantity to give spore coal.

The prevalence of *Vertebraria* makes probable that the peaty swamps, now represented by the coal seams, began as fern brakes with reeds. He had never seen a tree stump in the underclay. The swamps at length became Waldmoors, covered with Dadoxylon forests. These, at several horizons, were overwhelmed by showers of volcanic dust and drops of resin were preserved in considerable quantity within this dust.

Cannel occurs as lenses within the thick Greta seam; the oil shale or Hartley mineral occurs in like manner as lenses within the coal, These, at times, are of considerable lateral extent and occasionally that mineral forms a more or less persistent bench, in which the richness varies greatly. The character of coal is rarely the same throughout a seam, cannel, splint and bright bituminous being found frequently in the section of a single seam.

India.

The Permo-Carboniferous of India is exposed in isolated fields, large or small, within a strip, crossing Hindostan between parallels 19 and 24. These deposits, belonging to the Lower Gondwana, are divided into the Panchet, Raniganj, Barakar and Talchir, of which Panchet has been referred to the Trias. The Raniganj and Barakar are equivalent to the Upper and Lower Damuda and, in much of the region, are separated by a mass of clayey to sandy and carbonaceous shale, holding much clay iron stone. Coal is confined practically to the Damuda beds, there being only occasional carbonaceous shale and local seams in the Talchir. This lowest member consists of greenish, at times sandy or gravelly muds, frequently containing pebbles and large blocks of rock, so that, in places, there is a distinct bowlder bed. The variations of the Permo-Carboniferous can be made clear by examination of several fields from east to west.

The *Rajmahal* fields is northeast from Calcutta between the

Ganges and Dwarka Rivers. Ball[10] reports that the Talchir has no coal but has *Gangamopteris*. The Barakar, in the northern part of the area, consists of coarse, friable, feldspathic grits with white argillaceous shales and a few seams of inferior coal. False-bedded sandstones occur near the coals.

The *Jheria* field[11] is on the northerly side of the Damuda River and its easterly boundary is about 170 miles above Calcutta in Bengal. The Damuda and Talchir are not far from 6,800 feet thick. The Raniganj, largely sandstone, seems to be without coal, and the same condition marks the Talchir. Some carbonaceous shale in the latter has ill-preserved remains of plants, among which is a form closely allied to *Glossopteris*. The Barakar, consisting of clayey, sandy or carbonaceous shales and shaly sandstones, with grits and sandstones in the basal portion, has coal seams in all portions; but these are thickest in the coarse lower part. At all horizons, these are variable in thickness of coal and of partings; pyrite is abundant and the quantity of mineral matter renders the coal almost worthless.

On the Chat Kurree Jour, some seams are very thick; Hughes noted thicknesses of 50, 6, 5, 8, 13 feet. The thickest deposit is at the base and is a mass of shale and bad coal; but there is one seam, almost 5 feet thick, which is fairly good bituminous coal with only 11 per cent. of ash. Concretionary nodules were seen at several localities; the laminæ of the enclosing coal cross the concentric laminæ; the nodular coal is better than the enclosing material. The characteristic plants are *Glossopteris* and *Vertebraria*; no marine fossils were observed but there are freshwater limestones with *Melania, Paludina* and *Planorbis*. The seams are extremely irregular and appear to be of limited horizontal extent. Hughes is confident that the absence in so many places cannot be due to faulting and that the only explanation is that they are merely local deposits.

The *Raniganj* field is west from the Jheria and 120 to 160 miles northwest from Calcutta. There Blanford[12] found the Talchir rest-

[10] V. Ball, "Geology of the Rajmahal Hills," Mem. Geol. Survey of India, Vol. XIII, 1877, pp. 155–248.

[11] T. Hughes, "The Jheria Coal-Field," Memoirs, Vol. V., 1866, pp. 227–236.

[12] W. T. Blanford, "On the Geological Structure and Relations of the Raniganj Coal-Fields," *Memoirs,* Vol. III., 1865, pp. 1–195.

ing on gneiss. It has a bowlder bed on top and its shales and sandstone often have rippled surfaces as well as obscure impressions, suggestive of footprints. No coal was seen and the plants, which are not abundant, belong mostly to *Glossopteris* and *Cyclopteris*. The Lower Damuda (Barakar) has coarse to conglomeratic white sandstone at base, succeeded by coarse, micaceous shaly sandstone with seams of coal and shale, often thick. "These seams are irregular both in thickness and in quality; they frequently disappear entirely or pass into shale or even sandstone within short distances." The Lower Damuda is about 2,000 feet thick, a notable decrease from the Jheria field, where it is about 3,300. The ironstone group, overlying the Lower Damuda, is about 1,200 feet thick and contains no coal. The Upper Damuda (Raniganj) consists of sandstone and shale without conglomerate; its coal seams are less irregular than those of the Barakar. The whole of the Lower Gondwana to the top of the Panchet is practically conformable, the apparent lack of conformity at some localities being due to overlap.

The Barakar coal seams are, for the most part, poor in quality but vary in that as well as in thickness. At one locality, in northern part of the field, is a seam, 34 feet thick, with three benches of coal, 7, 14 and 11 feet, but the coal is poor and slaty except in one part of lowest bench. This great deposit can be traced for only a short distance and it thins away rapidly in all directions. Many thick seams were seen west from Barakar River. "These seams, however, seldom appear continuous over the whole area of the field; they can often not be traced for more than a few hundred yards and the quality of the coal may (and in general does) vary within even shorter distances." In one case a seam, 13 feet thick, divides into two within 50 yards, and the lower division soon is replaced with sandy shale. At times, sandstone and shale replace the coal for considerable distances. "Ballcoal" is not rare and the concentric laminæ are crossed by laminæ of the enclosing coal.

The Raniganj seams are less irregular and contain less shale. Blanford saw one 22 feet thick which was without parting, but ordinarily there are two or more benches. As a whole, the coal of this formation must be regarded as inferior; the 17 analyses show 8.50 to 35 per cent. of ash; only two samples had less than 10 and 6 had

more than 20 per cent. As the samples were clearly supposed to represent the average coal mined, they mark only the best and serve to indicate the general inferiority.

The *Aurunga* and *Hutar* fields are somewhat more than 100 miles west from the Raniganj field. There, according to Ball,[13] the Lower Gondwana is overlapped by the Machadeva or Lower Jura, which, west from the Aurunga River, rests on metamorphic rocks. There is no coal in the Talchir. Ball thinks that the Karharbari coals belong to the Talchir rather than to the Barakar, though the associated rocks are similar to those of the Barakar.

In the Aurunga field, the Barakar deposits are sandstone grits and conglomerates with huge seams consisting mostly of carbonaceous shale, which occur "at various horizons and with most irregular lateral expansion." The deposition was confused; overlaps are frequent; changes in character and thickness of individual deposits are abrupt; pebbly conglomerates pass into breccias. The Barakar is about 1,500 feet thick in this field and the coals are of inferior quality. In the Hutar field, the Talchir is overlain on the western side by conglomerates and sandstones, resembling those of the Lower Jura. Coal is present in the Barakar on the Dauri River and westward, but it is wanting east from that river. The great irregular seams are not here but, instead, there are thin seams, often yielding good coal; these are intercalated in the sandstones within a vertical space of about 200 feet.

In both fields, the Barakar overlaps the Talchir and the seams of coal and shale are often of notable thickness. In a section near Rajbar, only 271 feet long, Ball measured 9 seams, about 10, 12, 83, 7, 13, 13, 21, 12, 24 feet, consisting mostly of carbonaceous shale with many streaks of poor coal. A sample from one seam, which looked like good coal, had only 22 per cent. of fixed carbon but 50 per cent. of ash. Similar conditions exist on the Sukri River near Toobed, where two seams were seen, 77 and 36 feet thick. This coal zone thins away toward the southeast. A zone of rippled sandstone was seen near Toobed. In the Hutar field there are four seams, 1 foot 3 inches to 8 feet thick, with much carbonaceous shale

[13] V. Ball, "On the Aurunga and Hutar Coal-Fields," *Memoirs*, Vol. XX., 1880, pp. 1–127.

in each, but there is a greater proportion of good coal than in the Aurunga field. The ash in analyzed specimens is from 7.8 to 18.2 per cent., whereas in the Aurunga field it is 15 to 34 per cent. The rocks of the Hutar are as irregular as in the other field. The Raniganj consists chiefly of soft yellow false-bedded sandstone and contains a coal seam, one foot thick. Its coal has 2.5 per cent. of ash.

The *Ramkola* and *Tatapani* coal fields, west from the Hutar field, are part of a strip extending westwardly about 200 miles to Jabalpur on the Narbudda River and thence southeastwardly about 300 miles to near Sarbalpur on border of the Talchir field in Orissa. Griesbach[14] states that Talchir, very irregular in occurrence and filling hollows in the metamorphic rocks, consists of clays and sandstones with conglomerate at top. The extreme thickness is not far from 900 feet.

The Barakar, consisting largely of micaceous sandstone, often flaggy, often crossbedded, contains some variable coal seams, which occur in three zones, two midway in the formation and the other directly under the Raniganj. In one of the middle zones, he saw a seam, 7 feet thick, but within a short distance it is but 3 feet 6 inches, while farther west the horizon is represented by 17 feet of black shale with streaks of coal. This kind of variation seems to be characteristic of the Barakar coals. The formation is not more than 900 feet thick; its coal is practically worthless and much of it is lignitic. The Raniganj, about 1,200 feet thick, is made up of white feldspathic gritty sandstone and white shale. No coal has been discovered. The Barakar in this area is characterized by *Glossopteris communis, G. browniana, G. damudica* and *Vertebraria indica;* but the Raniganj has *G. communis, G. angustifolia* and *G. retifera.*

The *Wardha Valley* field is about 175 miles southwest from the last. It was examined by Hughes,[15] who found the Talchir and Barakar clearly defined but the ironstone shales and the Raniganj are indefinite; the term, Kamti, is applied to the rocks occupying

[14] C. L. Griesbach, "Geology of the Ramkola and Tatapani Coal-Fields," *Memoirs,* Vol. XV., 1880, pp. 129–192.

[15] T. W. H. Hughes, "The Wardha Valley Coal-Field," *Memoirs,* Vol. XIII., 1877, pp. 1–154.

the interval. Talchir, without coal, has the same features as in eastern fields; Feistmantel found fronds and seed vessels of *Gangamopteris,* which he separated from *Glossopteris.* This plant occurs also in the Barakar.

The Barakar is only 250 feet thick, whereas in the Jheria field it is 3,300. Coal is confined to a band near the top. At one locality, a boring pierced a seam, 48 feet thick, with 3 benches of coal, 30 feet, and 4 benches of coal and shale; coal taken from a bench 15 feet thick, proved to be good as fuel, but it splits on exposure and when wetted it crumbles. At another locality, the seam is almost 59 feet, with 44 feet of coal, but ash is almost 23 per cent., though there is some "less bad" coal in one portion with only 18. At still another locality, the seam is 81 feet, in two main benches, 37 and 32 feet. A specimen yielded 14.5 per cent. of ash. This mass, though generally thick, shows extreme irregularity and in many borings no trace of it exists. Hughes was not prepared to decide whether the explanation is to be found in erosion or in non-deposition, but was inclined to accept non-deposition, for many outcrops show the attenuated border of deposition, containing only shale with no disintegrated coal. The Barakar coal is bituminous, but, as a rule, it is inferior because high in ash and sulphur. No coal has been seen in the Kamti. No marine fossils have been discovered.

The southern part of the *Sátpura-Gondwána* Basin is about 140 miles north from the last and about 50 miles farther west. According to Jones,[16] the Talchir here is as in the fields at the east. Barakar coals are present in the numerous petty basins and the seams vary from a few inches to 11 feet; but the thicker ones are divided by clay partings. Occasionally, the coal has a sandstone roof. Mining is insignificant and there is nothing in the character of the coal to justify exploitation; analyses from six localities showed 17 to almost 49 per cent. of ash and only one specimen caked.

The Narbudda River reaches the Gulf of Cambay on the west coast of Hindostan near the 22d parallel; the *Narbudda District* is on the lower part of the river and is west from the Sátpura region.

[16] E. A. Jones, "Southern Coal-Fields of the Sátpura Godwána Basin," *Memoirs,* Vol. XXIV., 1887, pp. 1–58.

In the central part of the district, Medlicott[17] grouped the Permo-Carboniferous into Talchir, Lower and Upper Damuda. The Talchir has the familiar features and at most is about 600 feet thick.

The Lower Damuda (Barakar and Ironstone shales) has an extreme thickness of not far from 1150 feet. The rocks are mostly sandstone and sandy shale, but there is a considerable proportion of black shales. At times, the sandstones are rippled and often are crossbedded. The deposition was irregular; sandstones pass to shale abruptly. *Glossopteris, Vertebraria* and *Phyllotheca* are abundant at several horizons. The coal seams, for the most part are thin and, with one exception, are without value, while, at best, they are mere lenses. The Upper Damuda (Raniganj), about 150 feet thick, is composed of irregularly bedded clays and clayey sandstones. The coals are thin and of indefinite extent. A section obtained at the junction of the Machariva and Sher Rivers and extending 150 yards, illustrates the conditions:

(1) Sandstone not measured; (2) good coal, 3 inches; (3) soft sandstone, 3 feet; (4) coal seam, consisting of black micaceous shale, 6 inches, coal 2 feet, shaly coal, 6 inches, in all 3 feet; (5) hard sandstone, 3 feet; (6) blue clay, 4 feet. The black shale of (4) is cut out quickly by (3) and the shaly coal of (4) disappears within a few feet, while (2) and (3) are replaced with clay before the end of the exposure has been reached. *Glossopteris* is wanting in the Upper Damuda, its place being taken by cycads. The coal seams are wholly unimportant.

The Talchir beds in the *Thilmille* coal field of Sergúja have a thin seam of coal; but as a rule this formation is distinguished by absence of coal and even of carbonaceous shale. The Kharharbari coal group was included originally in the Barakar, but it was placed in Talchir by Medlicott and Blanford[18] because of the intimate relation of the flora.

In studying reports on the several coal fields one cannot fail to be impressed by the thinning of Raniganj, Barakar and Talchir from

[17] J. G. Medlicott, "On the Geological Structure of the Central Portion of the Narbudda District," *Memoirs,* Vol. XIII., 1877, pp. 155–248.

[18] H. B. Medlicott and W. T. Blanford, "Geology of India," Calcutta, 1879, pp. 109–112.

east to west; the apparent exception in the Narbudda district is only apparent, for Raniganj and Barakar are counted as one and the Panchet or Trias is the Upper Damuda. Equally noteworthy are the great irregularity and evidently local character of the coal seams, which are hardly less striking than the small proportion of high-grade coal in all of the fields.

Siberia.

Carboniferous deposits are exposed in broad areas within the Kirghiz Steppes of western Siberia.[19] There, according to the synopsis published by the Comité Géologique, the Lower Carboniferous rests at times on the Devonian, at others on the metamorphics. The lower portion is mainly limestone, but higher in the section the prevailing rocks are gray or green calcareous sandstone, with marine fossils similar to those of the limestone. This portion, however, varies greatly; in some localities it is chiefly shaly sandstone while in others it is mainly black clay shale.

Directly overlying the Lower Carboniferous is the Coal series, consisting of alternating white, gray to black, more or less sandy shale, with yellow to green and white clayey sandstones and some seams of coal. The white to gray sandstones occasionally become conglomerate, but only in limited areas. The only fossils are plants, which occur abundantly in the roof or near the coal; but these are ill-preserved and, in large part, only the genus can be determined; the flora, however, is distinctly Upper Carboniferous.

The coal-bearing rocks are in valleys, enclosed by older deposits and in most localities are greatly disturbed, though the disturbance is comparatively slight in a few areas. The variation in thickness of coal seams is almost as notable as in those of India. Borings made near Ekibas-touz, under supervision of the government geologists, revealed the presence of two seams, 23 and 40 meters along a line of 7 versts; but elsewhere the total of coal rarely exceeds 6 meters and, too often, the seams are merely alternating thin layers of coal and coaly shale, practically worthless for industrial purposes. The district between the Irtych and Ichim Rivers, south and west from

[19] Aperçu des Explorations Géologiques et Minières le long du Transsiberien," le Comité géologique de Russie, 1900, pp. 27–32, 52, 83–88.

Pavlodar on the Irtych, is marked by great irregularity in the seams; at Tyn-koudruk, one, 2 meters thick, thins away like a wedge, while another near by has coal charged with sand and thins away rapidly. Generally speaking, the seams are inconstant, at times swelling abruptly and at others disappearing. The variations do not appear due to the disturbance. The coal horizons, of which many were examined, occupy very limited areas. Some clean coal was seen, but there is little of it.

Eastward from the Ob River, one is beyond the Kirghiz Steppes. In the space between that river and the city of Atchinsk, the Lower Carboniferous is exposed frequently with, in general, the same features as farther west, except that some of molluscan forms found in the Ural region are wanting. The coal formation is triple and the seams are in the middle division, which consists of clays, shales and sandstones, with many remains of *Neuropteris* and *Cordaites* as well as *Anthracosia, Posidomya, Carbonicola* and other mollusks. The basin has an area of not far from 15,000 square kilometers and has many seams of coal but no attempt to develop them has been made.

An important basin is crossed by the railroad in the Jenessei region. Near Soudjenka, 130 kilometers from the city of Tomsk, this is 5 kilometers wide. It extends many miles northward, narrowing to disappearance; but it was followed for a much longer distance toward the south, with constantly increasing width. The dip is high, rarely as low as 10° and frequently as much as 60° to 90°. Nineteen seams of coal were seen, more than 0.75 meter thick, one of them 11 meters. The coal, mined somewhat extensively near Soudjenka, is much the same at all horizons; by some it would be classified with anthracite, while others would call it caking coal. Seams were seen at many localities on the Upper and Lower Angara River, north from Irkoutsk, everywhere characterized by irregularity of occurrence. The coal of this central region is much better than that of the Kirghiz Steppes, samples from Soudjenka and the Angara yielding only 3 to 6 per cent. of ash.

Cannel, 0.5 meter thick, was seen on the Ichim River, 60 miles north from the railroad.

Carboniferous deposits seem to be wanting in the region east from Lake Baikal.

Russia in Europe.

Murchison[20] believed the Carboniferous System of northern and central Russia to be equivalent to the Mountain Limestone and underlying deposits of Great Britain, while, on the western slope of the Urals, he recognized the Millstone Grit and Permian. In the Valdai Hills, Province of Novgorod, the Lower Carboniferous consists of, ascending,

Lower Limestone, with *Productus gigantea,* associated with sands and some coal beds; Moscow Limestone with *Spirifer mosquensis;* it has no coal in northern and central Russia, but there are seams in the southern Steppes; Upper Limestone, with *Fusulina cylindrica,* containing coal only in the southern Steppes.

The sands at base of the Lower Limestone have many pyritized plants, among them *Stigmaria ficoides;* bituminous shales associated with the sands contain coal. Those on the Pritchka River are 40 feet thick and contain 4 coal seams in the upper portion. The coal is extremely imperfect and is from 10 inches to 4 feet thick. Helmersen had described this as Moorkohle; it is impure, pyritous, slightly consolidated and is inferior to some Tertiary coals mined in portions of Germany. The cover is largely loose sands and variegated marls.

Nikitin[21] states that the lignite occurs in the Toula District near the Volga. The coal group, at same horizon as in the Valdai Hills, consists of alternating clays and sandstones with more or less considerable seams of coal. He thinks it strange that this material, in spite of its great age, has chemical and physical character so closely allied to that of lignite. Boghead, rich in oil, is present at several horizons. At one locality, several thin coals were seen at the base of the Lower Carboniferous, but they have insignificant lateral extent.

[20] R. I. Murchison, "Geology of Russia in Europe and the Ural Mountains," London, 1845, Vol. I., pp. 69–71, 78, 126.

[21] S. Nikitin, "De Moskau à Koursk," Guide des Excursions, XIV., St. Petersburg, 1897, pp. 4–7.

The Donetz coal basin in southern Russia was studied in 1892–94 by Tschernyschew and Loutougin,[22] who published a synopsis of their reports. The Basin occupies much of the provinces of Poltawa, Kharkow and Don Cossacks, and is drained by the Donetz River, emptying at northeastern corner of the Sea of Azov. The Carboniferous is exposed in an area of not far from 12,000 square miles, but borings through overlying deposits prove that the actual extent is much greater. The deposits are, as described by Murchison, in three divisions, but the highest one belongs to the Upper Carboniferous. The divisions are designated C_1, C_2, and C_3, in ascending order. The measurements by Tschernyschew and Loutougin are in great detail and the description notes the lithological character and fossil contents of each stratum. Condensed, the description is C_1, in its lower 4 subdivisions, consists of limestones and silicious marls, rich in marine fossils. Coal appears first in the 5th, composed of gray micaceous sandstone with subordinate beds of limestone, arkose and shale; the coals are thin. C_1 is characterized by *Productus giganteus*.

C_2 begins with a mass of sandstone, shale and limestone, in which *Productus giganteus* is wanting and *Spirifer mosquensis* is the notable form. Coal occurs in the second subdivision, but the seams rarely attain workable thickness. The third, shales, sandstones and insignificant limestones, has 9 coal seams from 0.35 to 0.75 meter thickness; though rarely reaching the maximum and varying greatly in thickness, several of these seams are mined extensively. At some localities they are excellent for coke, at others for gas, while at others they are anthracitic. Usually only one or two beds are "workable," but at Ouspenskoïé, there are 8. The fourth subdivision, 320 to 350 meters thick, almost wholly sandstone and shale, has 4 seams, rarely workable and often replaced with shale. The fifth, 250 meters thick and composed of sandstone and shale with about 6 meters of limestone, has 8 seams and is richer in coal than are the lower subdivisions, though the seams are very irregular. The extreme thicknesses in the important seams are 0.7 to 1 meter, but these in some cases thin away to insignificance. The sixth, 225

[22] T. Tschernyschew and L. Loutougin, "Le Bassin du Donetz," Guide des Excursions, XVI., 1897, pp. 4–10, 12–23, 27–29, 34, 50.

to 300 meters, is the most important coal-bearing portion. Of the 11 seams reported in the section, 8 have a maximum of 0.7 to 1.75 meter inclusive of partings. Marine fossils were observed in the roof of 5 seams.

C_3, about 2,000 meters thick, contains workable coal only in the lower horizons. The fauna changes gradually; forms of the middle division disappear and new forms appear, which are characteristic of the Upper Carboniferous in Timan and in North America. The lowest subdivision has 10 seams, but all are thin and the coal is poor. In one case, the roof contains marine fossils. Red to green shales are in the upper part of the section. The second is separated from the first subdivision by 11 meters of marine limestone and contains 2 or 3 coal seams, which are wholly unimportant. Arkose near the base has fragments of *Araucaria* and the section shows some green and red shale. The third subdivision has only thin streaks of coal and thin beds of red shale. The fauna and the flora are distinctly Upper Carboniferous.

The number of coal seams, which, at some place, attain workable thickness, is not more than 30; but the variability both in thickness and in quality is extreme; some disappear, others become thin and worthless while new ones appear. The coal loses volatile in the direction of increasing dip. At mines in the Almazny seam, along a northwest-southeast line, only 20 miles long, the volatile is 35, 30, 25, 18, 15 or less per cent. The proportion of volatile has no relation to nature of the roof or floor. The authors regard the Donetz coals as allochthonous, the convincing argument being the presence of marine fossils in the immediate roof of coal seams.

Permo-Carboniferous deposits are confined to the western side of the Donetz Basin, where they rest directly on the limestone closing-C_3. Deposition was continuous from Carboniferous to Permian and there is no evidence of unconformity anywhere. The deposits are regarded as Lower Permian and the abundant marine fossils are in greatest part forms characterizing the C_3, the Upper Carboniferous; the change in fauna is as gradual as that in passing from C_2 to C_3. The lower portion consists of clayey shales and gray, green or red limestones with some streaks of coal near the base. The upper portion consists mostly of red and green marls

with deposits of salt and gypsum. Some dolomites, regarded as equivalent to the Zechstein, were seen at one locality. These contain a Permian fauna. Disturbance followed the close of the Permian, and the overlying rocks are notably unconformable, occupying valleys in the eroded Paleozoic rocks.

Conditions in the southern Urals are much as in the Donetz Basin. Murchison[23] described them in his great work on Russia. At a later date he gave a synopsis of his conclusions, in which he states that the Permian deposits "occur in almost apparent conformity to the Carboniferous rocks." Coal appears to be wanting in Urals but the lower division contains streaks of impure coal in the central region between the Urals and the Volga River.

Spitzbergen.

Nathorst[24] has given in summary the results obtained by himself and others during exploration of the Spitzbergen region. The whole series from Lower Carboniferous to the Permian is present. The Lower Carboniferous, which is represented by the Kulm, rests unconformably on the Devonian. It consists, at base, of dark quartzitic sandstone, underlying yellow sandstone, on which rests a mass of bituminous clays and shale with fragments of ferns and, in the lower part, a thin seam of coal resting on a *Stigmaria* underclay, containing sphaerosiderite. Above this mass of shale and clay are sandstones, yellow and white, becoming red in the upper portion, showing coaly streaks at some places and at others lenses of coaly shale resting on *Stigmaria*-clay. The lens form is due to compression. The dip approaches 90°. The petrographic characters as well as the fossils indicate that the Kulm beds were deposited in shallow fresh-water. They suggest swamps at mouths of rivers.

The Kulm beds are followed by a mass of limestone, which, at base, shows transition to the Upper Carboniferous, and at top to the Permian. The system closes with rather loose marls and sandstones, holding less than 2 meters of limestone in the thickness of

[23] R. I. Murchison, "Siluria," 3d ed., London, 1859 p. 325 et seq.

[24] A. G. Nathorst, "Beiträge zur Geologie der Bären-Insel, Spitzbergens und des Konig-Karl--Landes," *Bull. Geol. Inst. Upsala,* Vol. X., 1910, pp. 321, 323, 325, 327, 330, 337, 347–350.

more than 30 meters. The total thickness of Carboniferous may be not far from 1,000 meters, as the maximum; but the several members vary greatly. Nathorst shows that throughout the whole section deep-water deposits are wanting. The Kulm, in greatest part, is of fresh-water origin; the limestones, beyond doubt, were laid down in shallow water during the long-continued slow subsidence of the area. The fossil wood is of a type indicating a sub-tropical climate. The deposits are conformable, the only irregularity being due to overlap.

Silesia.

The Upper Silesian Coal Field.—This extremely important field is between meridians 18° and 20° and is divided toward the southern border by the 50th parallel. In greatest part, it is within Prussian Silesia, but it extends eastwardly into Galicia and westwardly into Austrian Silesia. The area is almost 4,000 square miles, of which 2,400 are in Prussia. The great economic importance of this field has led to many careful and more or less detailed studies during the last eighty years. According to Dannenberg,[25] the deposits have been grouped into

V. Saarbrück Stage	Sohrau beds		
IV.	Nikolai bed	Karwin or Orzesch beds	
	Ruda beds		
III. Sudetic Stage (Waldenburg)	Sattelflötz beds		
II.	Czenitzer beds		
	Loslauer beds	Rybnik beds	Ostrau beds
	Hultschun beds		
I. Lower Carboniferous	Golonog beds		Petrzkowitz beds
	Kulm		

The Ottweiler stage is wanting and the presence of Permian is uncertain. The grouping is essentially that offered by Gaebler in 1898. Somewhat later, Michael[26] used other terms: Instead of Saarbrück he employs Mulden, as it occupies the central part of the field; Satterflötz is replaced with Sattel-group, while the Ostrau

[25] A. Dannenberg, "Geologie der Steinkohlenlager," Erster Teil, Berlin, 1908, pp. 170–172, 180–197.

[26] R. Michael, "Die Gliederung der oberschlesische Steinkohlenformation," *Jahr. k. k. preuss. Geol. Landesanst.* Band XXII., 1902, pp. 319–340.

beds are termed the Rand group because they are on the border of the field. The Rand or Ostrau beds form the Schlesische Stufe.

Dennenberg has given a careful synopsis of his observations and of those by other students in this region, which may be utilized here. The thickness of the Saarbrück and Sudetic stages is, at most, not far from 7,000 meters; but the coal is distributed unequally. The Sattelflötz, at most barely one-twenty-eighth of the whole mass, contains about one fifth of the workable coal. The deposits decrease toward the north and east, the Sudetic mountains being the source whence the sediments were derived. The Sattelflötz beds near Zabrze measure 240 to 250 meters but at the east, on the Galician border, they are only 14 to 15 meters. According to Gaebler, the Ostrau or sub-Sattelflötz beds are 4,000 meters thick near Ostrau at the southwest, but only 500 meters near Golonog on the extreme northeastern border of the field. The total of Upper Carboniferous diminishes from about 7,000 meters at the west to barely 1,220 at the east. This thinning of sediments leads to frequent disappearance of intervals with resulting union of coal seams and relative enriching in coal-content.

The Upper Carboniferous rocks in this field are remarkably uniform in general character; sandstones, mostly white, prevail; while shales are subordinate and become important only in the highest division. Clay ironstone is present in nodules or in workable beds. Conglomerates are insignificant and red beds are practically wanting. The maximum thickness of the several divisions is Saarbrück (Karwin or Orzesch), 2,700 meters; Satterflötz beds, 240 meters; Ostrau beds, 4,070 meters. The total of coal is 299 meters, of which only 169 are in workable seams.

But emphasis must be laid on the fact that this statement of coal resources is merely general and is the maximum. The number and thickness of coal seams vary from place to place; the Ostrau beds are usually barren in the northern parts of the field, but there are a few seams which occasionally become workable. The Satterflötz beds, "the glory of the field," show extreme variation. They are exposed by anticlines in the neighborhood of Zabrze, Konigshütte and Myslowitz, but elsewhere in the greater part of the Prussian area they are buried deeply. The chief expansion is at Zabrze on

the western side but thence, northward and eastward, the changes are as interesting as those in the Anthracite region of the United States. Five seams are mined at Zabrze; but just west from Beuthen, one finds that the thick parting between numbers 1 and 2 and the interval rocks between 4 and 5 have disappeared; at Konigshütte, the 3d seam has become united to 4 and 5, so that now there are but the Upper seam, representing 1 and 2, and the Lower seam, representing 3, 4 and 5. But, at a short distance farther west, near Kattonitz, these two seams are so near together that they are mined as one. At the west, the coal of Sattelflötz beds is to the other rocks as one to nineteen, but at the eastern border it is thicker than the other rocks. Whether or not the newer seams overlap the older ones after union does not appear from the reports.

The same features are shown by the Saarbrück complex, which is present chiefly in the central portion of the field. Near Nikolai, Sohrau and Pless, it is 2,667 meters thick, with at least 253 coal seams, 45 being workable with about 75 meters of coal; but near Beuthen, 20 miles north, the Ruda beds, which near Nikolai are 589 meters thick with 49 meters of coal, are only 248 meters with 11.93 of coal; while in the Galician region the whole Saarbrück is but 1,014 meters with 35 seams and somewhat more than 60 meters of coal. The Ostrau-Karwin region is in Austria. The Ostrau beds occupy the Ostrau trough and most of the Peterswald. The Sattelflötz beds, as shown by Petrascheck and Mladek since the publication of Dannenberg's work, are present in the west side of Karwin trough, passing under the Saarbrück farther east. Marine deposits are characteristic of the Ostrau beds here as also in the northern areas. The number of coal seams is great and the quantity of coal makes the district important—in contrast with the other districts, where the Ostrau coals are almost unimportant.

Goeppert,[27] three-quarters of a century ago, studied the Silesian and Galician portions of this region. His investigations were made largely from the paleobotanist's standpoint, so that he had little interest in correlation and still less in economic studies.

Conglomerates are not wanting but the pebbles are rarely larger

[27] H. R. Goeppert, "Abhandlung eingesandte als Antwort auf die Preisfrage, etc.," Leiden, 1848, pp 107–206.

than a pea; the prevailing rock is sandstone, gray to yellow, which in some localities weathers to a carved or fretted surface. It is quartzose and has little cementing material. Clay shales are intercalated in the sandstone mass and they are associated with the coal seams. Near the coal, these shales often are rich in bitumen, becoming Brandschiefer and frequently containing much pyrite. Irregularity of deposit is evident from the rapid change of sandstone into clay shale. Sphaerosiderite occurs chiefly where the coal seams are thin and alternating with shaly clays.

This region is marked by the thickness, extent and regularity of the coal seams, according to Goeppert; but when he studied the area, the correlation was very uncertain. The thickness is from 3 to 12 feet, but at one locality it reaches 42 feet. About 20 seams are workable. Dips commonly are less than 12°, but near the Carpathians they are higher. The thicker seams are ordinarily in several benches, varying not only in thickness but also in character of the coal; some benches are caking, others, not. Laminated coal is the predominant type and occurs, as a rule, in the top and bottom portions; Grobkohle forms the best benches of thick seams and for the most part is confined to the middle, being found rarely in other parts; clean Pechkohle is less abundant and Blätterkohle seldom occurs. In great districts, every coal seam contains remains of plants, especially of *Sigillaria;* Faserkohle is in all seams and sometimes it predominates, making the coal loose.

At Zabrze, the seams [Sattelflötz] contain much Faserkohle; that material predominates in the highest, which is 13 feet thick. A sandstone quarry in the Brenz district, on the Poland border, has great stems of silicified wood—an unusual occurrence in the Upper Silesian field. Near Myslowitz he saw *Sagenaria* stems standing on the coal, one of them 4 feet high and 2 feet in diameter. In the Locomotive mine, there, erect *Sigillariæ* are abundant in the roof of the coal seams. On the Poland border, the lowest seam near Dabrowa is 78 feet thick, divided midway by 6 feet of Brandschiefer, consisting of compressed *Sigillaria* associated with a little clay. The same *Sigillaria* is in the coal along with Faserkohle. Goeppert states that the *Sigillaria* is incredibly abundant.

At Zawada in the Nikolai district [Saarbrück], the Friedrich

mine works two seams, 24 and 60 inches thick, separated by an interval of 48 to 54 feet. The lower yields a laminated, hard, coking coal but coal from the upper one was considered to be inferior. When the lower seam was almost exhausted, work was begun on the upper. Its coal resembles Blätterkohle, consisting of hard, glance-like lamellæ alternating with thinner dull laminæ, composed of compressed barks of *Lepidodendron, Calamites, Stigmaria* and *Sigillaria,* all distinct. Goeppert states that, in many ways, this resembles peat. At a mine in this Nikolai district, the coal contains great abundance of *Sigillaria* and *Lepidophloios* and an "incredible" mass of *Sigillaria* is in the roof. There he obtained *Sigillaria* and *Alethopteris* with leaves only slightly brown and completely flexible, preserving the minutest details of structure. Union of coal seams is a familiar feature in the Nikolai district. Additional observations by this author will find place in another connection.

Goeppert makes only passing reference to the Austrian part of the field; but material information respecting one portion has been given by Petrascheck[28] in a paper dealing especially with the Peterswald trough, lying between the Ostrau trough at the west and the Karwin trough at the east. With Stur and Gaebler, he recognizes Ostrau beds in the western part of the trough but he finds the Sattelflötz beds in the eastern portion, where the disturbance was so severe as to cause inversion. A serious difficulty encountered in correlation was found in the sudden changes in character as well as thickness of the deposits, which mark some horizons more than others. It appeared to him that the Ostrau beds were deposited on a rudely level oscillating coast, so that paralic and limnic conditions alternate. In discussing the evidence of overturned stratification, he presents some facts which have interest here.

The layer of "Schramm," soft, more or less clean coal, passing at times into shale, is, as a rule, on the floor of the coal seams; occasionally, it is found in the body but very rarely on top of the coal. In the Sophien coal mine, all coal seams have the "Schramm" on top, the Faux-mur having become the Faux-toit. Reed-beds or underclays with *Stigmaria* appendages crossing the bedding, are the

[28] W. Petrascheck, "Das Alter der Flöze in der Peterswalder Mulde, etc.," *Jahrb. k. k. geol. Reichsanst.,* Band 60, 1910, pp. 779–814.

roof, not the floor of the seams in their present position. In one seam, upright stems stand on the coal, in the present floor, but original roof. The note on Cannel is worth citing, as it indicates unusual conditions in the area. There one finds in the upper seams of the Ostrau as well as in the Karwin seams, lenses of cannel or of dense cannel-like Brandschiefer, "Sklok" of the miners. Petrascheck states that, as a rule, this is the top of coal seams; he knows of only one instance where it is at the bottom. This he regards as the ordinary condition in coal regions, thus taking issue with Potonié, who maintains that it occurs usualy at the bottom of seams. But in the American coal areas, cannel is found in any part of coal seams, just as the analogous material is found in peat deposits.

The Sattelflötz area, farther east, is thick, consisting mostly of sandstone and arkose with intercalated beds of red sandstone. The important coal seams have been correlated definitively with the main seams of the same group in upper Silesia. The evidence was obtained in three borings. Marine forms are present at 20 feet below the Prokop (Pochhammer) seam and they mark the top of the Ostrau. At Justin, the coals have local cannel in Hangend. Splendid, widespreading, branching *Stigmaria* are in the floor of the Ivan seam, associated with sphaerosiderite. Seam II. has cannel-like coal near the top, covered with black coal, underlying a shale with marine mollusks. Erect *Sigillaria* were seen in the roof of the Hermann seam.

At the Albrecht shaft, the Eugen seam has many prostrate as well as erect stems in the roof and indistinct *Stigmaria* are in the floor. Stur found pebbles in this coal. Long ago, Bartonic collected from a dark shale in this seam a marine fauna, *Nucula, Pleurotomaria,* and *Orthoceras* as well as *Anthracomya.* The Koks seam contains plant-bearing concretions of iron stone and a layer of shale with similar concretions rests directly on the coal; it too has a marine fauna. A sandstone near the Koks seam has so great number of stems of *Lepidodendron* and *Sigillaria* that Petrascheck regarded it as a strand formation. Pebbles were seen in the younger Ostrau coals. They are numerous in the Josefi coal, granite, porphyry and quartz; they are present also in the Kronprinz seams but are smaller than in the other. Erect stems occur in the

roof of the Juni seams. Cannel-shale and sphærosiderite are characteristic and several marine horizons were observed.

Petrascheck[29] has called attention to the occurrence of coal pebbles in a sandstone at Brzescze in the Galician area. This sandstone, containing many fragments of *Sigillaria,* is shown in the Andreas shaft and belongs to the Upper Schatzlar [Saarbrück]. This sandstone for the most part is moderately coarse, but, where the pebbles of coal occur, the grain is coarser, almost conglomerate. Many of the coal fragments are well rounded, others have rounded angles while in others the edges are still sharp. Along with these are streaks of coal, insignificant in extent, and fragments of shale were seen. The lamination of the coal pebbles does not coincide with that of the sandstone. The largest pebble seen measured 6 by 5 by 3 centimeters.

The fragments include glance and laminated coal as well as cannel and show the peculiarities of each type; glance fragments are sharply angular but those of cannel and laminated coal are more or less rounded. Petrascheck is convinced by the form and structure that these were not balls of peat or pieces of wood, when entombed. For him, the evidence indicates clearly that the several types of coal seen in the pebbles had attained their characteristic features in Carboniferous time. The fragments are unquestionably of Canboniferous age for no older coal-bearing series exists anywhere in the surrounding region; but the source has not been discovered.

The Lower Silesian-Bohemian Basin.—One reaches this basin at about 150 miles north of west from the Upper Silesian field. The area is not far from 750 square miles; originally it was open toward the southeast, but was closed at the north and west by the Riesengebirge and at the east by the Eulengebirge. The northwestern and eastern portions are in Silesia but the southwestern, including much of the interior basin, is in Bohemia. The region was studied in great detail by Goeppert and recently Dannenberg[30] has summarized

[29] W. Petrascheck, "Das Vorkommen von Steinkohlengeröllen in einem Karbonsandstein Galiziens," *Verh. k. k. Geol. Reichsan,* 1910, pp. 380–386.

[30] H. R. Goeppert, "Abhandlung, etc.," 1848, pp. 207–275; A. Dannenberg, "Geologie der Steinkohlenlager," 1908, pp. 147–184.

the results of his own investigations with those of other observers. According to Dannenberg, the Lower Carboniferous of the Kulm stage is present in the Waldenburg district on the northern and eastern sides; it consists chiefly of coarse material but sandstone and shale are in the upper part, with occasional limestone. The colors are gray, brown and red. Organic remains are rare and the few animal remains belong to marine types.

The Upper Carboniferous, resting unconformably on the Kulm, is a monotonous accumulation of conglomerates and sandstones; these are usually almost white, but locally in rather wide spaces these beds, owing to infiltration of iron salts, are red and very similar to Rothliegende. The proportion of shale is remarkably small and it is found almost wholly in association with seams of coal. The divisions are

Radowenz beds	Upper Ottweiler
Schwadowitz beds	Lower Ottweiler
Schatzlar beds	Saarbrück
Waldenburg beds	Sudetic

Marine fossils are absent and the only animal remains belong to fish, phyllades and ostracoids, which may be either fresh-water or brackish water-forms. The Rothliegende boundary cannot be determined; Coal Measures pass upward gradually and, in the southwest wing of the basin, the similarity of the rocks is so great that Upper Carboniferous was mistaken by some observers for Rothliegende. Local discordance has been discovered here and there in the Upper Carboniferous, there being local gaps in the succession; similar discordance between Upper Carboniferous and the Rothliegende has been observed, but evidence of general discordance between Upper Carboniferous and Permian remains to be discovered.

Groups of workable coals are in all the stages, but they are separated by thick deposits of barren rock. The irregular deposition of the several stages and the notable variations in thickness of coals lessen greatly the importance of this field. No coal seam is persistent throughout the exposed area of its stage; each decreases in all directions from a maximum and not a few seams disappear. No definite relation exists between depth from surface and the

character of the coal; maigre and caking coals alternate, but in a general way there is more of fat coal in the higher than in the lower divisions. Formation of coal began during the Kulm, which, on the northern and northwestern border, contains streaks of anthracite, up to 10 inches thick, associated with coaly shale. But accumulation was unimportant prior to the Sudetic stage.

The Waldenburg (Sudetic) beds are the Liegendzug at Waldenburg; workable seams in the eastern part of this district are few, thin, dirty and varying much in thickness. Just beyond Altwasser, 16 seams were seen, of which 6 to 13 are workable in the several mines. Farther toward the south, only one seam is workable—and locally—near Tannhauser, the whole stage thins away. The seams are 10 to 50 inches thick.

The Schatzlar (Saarbrück) stage is the Hangendzug at Waldenburg and is separated by a thick practically barren interval from the Liegendzug. The rocks in this interval are conglomerates at base, passing upward into coarse sandstone with some shale and thin streaks of coal. These are overlain by the Hochwald porphyry, which is 834 meters thick west from Waldenburg. The rocks below the porphyry are the Weisstein beds of Dathe.[31] The Schatzlar stage is important chiefly near Schatzlar in the western part of the field within Bohemia. Northeastward from that locality to Landeshut the coals are insignificant; but toward the southwest workable seams are at Gottesburg. Along the northern outcrop in Prussia, the stage is unproductive, but at Waldenburg the seams are numerous once more and 12 to 15 out of the 40 shown in the section are workable with maximum thickness of 2 to 4 meters. But here as elsewhere workable thickness never occurs in any considerable space and important localities are practically isolated.

The Schwadowitz and Radowenz, representing the Ottweiler, are exposed in the southwestern part of the field, where the coal seams are of merely local importance. The succession, descending, is:

Radowenz, enclosing 5 to 7 seams, of which 2 are workable locally;

[31] E. Dathe, "Der Verbreitung der Waldenburger und Weisssteiner Schichten in den Waldenburgen Bucht," *Verh. d. d. Geol. Gesellsch.*, 1902, pp. 189–193.

Barren interval, "Hexenstein Arkose," alternations of arkose, conglomerates, sandstones, and clay shale, with stems of *Araucarites schrollianus* (beds of the petrified forest);

Schwadowitz beds with 3 to 5 seams, 2 of them workable locally.

The prevailing color of the Ottweiler is red, but in the clay shales it is gray.

Goeppert[32] described the remarkable accumulation of petrified stems in the Hexenstein arkose. This is exposed on a high sandy ridge, extending northwestwardly from Radowenz to beyond Schatzlar. The fragments, weathered out from the soft sandstone, are extremely abundant in an area of not far from 20 English square miles. All of the stems seem to be prostrate and lie in practical conformity to the bedding of the sandstone; but they show no evidence of transportation such as should be expected if they had been washed out from their place of growth. The conditions led him to believe that the fragments are the remains of an overthrown forest. Those lying exposed on the surface have diameter of 1 to 4 feet, with a round or oval section and they are not waterworn; the length is from 1 to 6 feet, though in some cases it is 14 to 16 feet. The stems belong to *Araucarites schrollianus* and *A. brandlingii*. Petrified stems are numerous near Schatzlar as well as at some other localities, but the great accumulation is at Radowenz.

In his earlier work on the eastern side of the field, Goeppert divided the area into two districts, Waldenburg at the north and Neurode at the south; but these are continuous. The dips are high, usually between 45° and 70° and the whole region was disturbed greatly by porphyry outbursts. Conglomerate, almost wholly wanting in the Upper Silesian Field, and coarse sandstone prevail; but these coarse rocks are not in contact with coal seams. The number of seams is greater than in the other Silesian field, but "rest periods," during which shales and coal accumulated, were brief and irregular; so that, while the maximum thickness of coal is great, the available quantity is comparatively small. In Upper Silesia, the coal seams consist chiefly of tree-like *Lepidodendron,* some *Sigil-*

[32] H. R. Goeppert, "Ueber den Versteinden Wald von Radowenz bei Adersbach in Böhmen, etc.," *Jahrb. k. k. Geol. Reichsan.,* Band VIII., 1857, pp. 725–738.

laria, a smaller number of *Calamites* and still fewer ferns; but in the field of Lower Silesia, though tree-like *Lepidodendron* and *Sigillaria* are not wanting, the prevailing forms are *Stigmaria, Equisetum* and ferns. Cannel-like coal occurs in the lowest seam.

From the Silesian-Bohemian line to beyond Altwasser, the Carboniferous rests on Transition rocks, but beyond Altwasser, usually on gneiss and mica schist of the Eulengebirge. In this, the Waldenburg district, the Hangend is red sandstone with occasional layers of limestone, containing fish remains but no plants; coal appears to be wanting but a black bituminous shale, 24 to 30 feet thick, is plant-bearing.

The lower coal group (Waldenburg) has many coal seams with a maximum thickness of about 43 feet, but the variations are great. A seam near Albendorf, 22 inches, splits into layers an inch to a half inch thick, of which the surfaces are covered with *Stigmaria ficoides.* Mineral charcoal is not abundant in this coal; the sandstone contain much petrified wood. Another seam, near Forste, yields a hard bituminous coal but the numerous clay parting make the seam almost unworkable; the coal contains *Stigmaria, Sigillaria, Sagenaria* and *Calamites.* The roof shale usually has a varied assemblage of plants, but at one locality *Calamites* is predominant. Goeppert saw, in the sandy roof of the highest seam, 4 vertical stems of *Sagenaria,* without roots, standing on the coal. In their interiors he found remains of *Calamites.*

Near Altwasser this group has 37 coal seams, but near Wäldchen there are only 2. Near Ober-Altwasser, 15 seams were seen, of which 6 can be worked, being 20 to 30 inches thick; but the dip is high, 60 to 70 degrees. Ordinarily, the coal in this neighborhood is laminated and, when split, the surfaces show *Stigmaria ficoides* as well as *Sigillaria, Sagenaria* and *Calamites.* The roof of seams 2 and 10 is, in each case, a mass of *Alethopteris* fronds, closely packed and associated with a very little clay. This condition was found persistent for 4,800 feet in one mine on seam 2. *Stigmaria* abounds throughout this lower group, not only in the clays, but also in the coal itself. Goeppert emphasizes many times the difference in species observed in superimposed coal seams as well as in the

same seam at different localities. Evidently there was localization of contemporaneous floras.

The upper coal group, above the Hochwald porphyry, has 80 seams of coal, 2 inches to 6 feet thick, but only 3 or 4 are workable, as partings are numerous. There are two subgroups, separated by a barren interval.

In the lower subgroup, he found resin by no means rare in seam 1; seams 4, 5 and 11 are caking; seam 6 has Sandkohle and seam 9 consists of Sinterkohle. Four has many thin layers of mineral charcoal; 11 is divided in distinct benches by partings of that material; but 5 has very little of it. The mineral charcoal is derived from *Araucarites* wood. *Stigmaria* is present in the coal at one mine; the upper bench of another seam contains *Sigillaria, Sagenaria* and *Stigmaria*. The southward prolongation of one seam has an abundant flora, which differs materially from that found in the northern prolongation.

The upper subgroup has 19 coal seams and the dip is 18° to 20°. The coal contains *Sigillaria, Sagenaria, Lepidophloios* and much mineral charcoal, the last in fragments up to 6 inches long. Resin is in the coal of a mine near Waldenburg. Erect stems of *Sagenaria* are in the roof of seam 9 and petrified wood was seen in a sandstone quarry. At the Sophien mines, the coal shows *Stigmaria* and *Sagenaria* on the surfaces of splitting; in the same neighborhood, another seam rests on clay, crowded with *Stigmaria* and its roof holds an abundant and varied flora. At the Fund mine in Charlottenbrunnen, the roof of a seam is a compact, fine-grained sandstone, in which he saw great prostrate stems of *Lepidodendron* and *Sigillaria*, 40 feet long and 30 inches in diameter. The floor has abundant *Stigmaria* and occasional *Calamites*. Many *Stigmaria* with some *Lepidodendron, Calamites* and *Noeggerathia* were seen in coal at the Segen-Gottes mine. The flora of this sub-group is most abundant, where the coal is thickest, but many types are confined to very restricted areas.

Similar conditions prevail in the Neurode district, where the higher deposits are reached. Near Buchau he saw in sandstone, several clumps of *Araucarites* stems, all apparently prostrate. Near

Ebersdorf, erect stems, probably *Sagenaria,* stand on the coal. At Mölka, he obtained *Unio carbonarius* from a clay containing ferns and lycopods.

Hungary.

The coals of Hungary,[33] confined to the Banat region, belong to the highest part of the Upper Carboniferous and to the Rothliegende. They are unimportant and are present in four isolated districts, Eibenthal-Ujbánia at the east, Lupak-Gerlistye, Resicza-Szekul and Zagradia at the west. The deposits in the Ujbänia district are exposed in an area of not more than 800 by 1,700 meters and rest on gneiss and serpentine. Hantken's section, ascending, is

(1) Fine-grained sandstone, micaceous, with many ill-preserved plants, no ferns, but *Stigmaria ficoides* and *Calamites cystii,* 10 to 15 meters; (2) Donau coal seam, 1.5 to 14 meters; (3) porphyry, the immediate roof of the Donau and floor of the next seam, 30 to 50 meters; (4) Wenzel coal seam, 20 to 40 meters; (5) iron ore and porcelain jasper, underlying the Rothliegende conglomerate.

The Donau coal seam varies abruptly and frequently passes into a bituminous clay shale, known as "Brand"; when thick it is divided by 16 to 50 inches parting and laminæ of clay are so numerous in the coal as to make the product inferior; but selected coal is good, showing: water, 2.17; volatile matter, 14.64; fixed carbon, 79.75; ash, 3.62; and sulphur rarely exceeds 1 per cent. The coal is tender and the loss in mining is 50 per cent. The section at the Donau mine is: (1) Clean coal, 0.32; (2) parting, 0.20; (3) less clean coal, 1 meter; (4) coaly shale, "Brand" 20 meters. This seam disappears toward the west.

The Wenzel seam yields harder coal than that from the Donau, but it varies much in thickness and quality; only the upper portion is mined. The variation in thickness in both seams is so abrupt that systematic mining is impossible and the coal is taken out wherever it seems to be good.

No workable seam has been found in the Upper Carboniferous of the Lupak-Gerlistye district but the Rothliegende, consisting of

[33] M. Hantken, "Die Kohlenflötze, etc., der Ungarische Krone," 1878, pp. 24–44.

sandstones and clay shales, has some seams which occasionally attain workable thickness. Coal seems to be confined to the lower portion which is made up of mostly dark clay shale; the middle division is chiefly red sandstone but contains some dark shale, yielding plants; the upper division, red sandstone and micaceous shale, contains *Walchia, Taeniopteris, Pterophyllum, Callipteris* and other genera. The Zagradia district has no available coal.

The Szekul Valley is west from Resicza. The Coal Measures are exposed in a small area, where they rest on gneiss and underlie the Rothliegende. The boundary between Upper Carboniferous and Rothliegende cannot be determined as the passage from one to the other is exceedingly gradual, lithologically, and there is no unconformity. Four seams of coal are in the Coal Measures with maximum thickness of 0.75, 2, 1.50 and 1.30 meter, but the variations in thickness are so abrupt that, in each case, the coal is available in very limited spaces. The dip is not far from 45°, but changes in thickness are due in small degree to the disturbance. Partings are numerous; those of the third seam are blackband, which at times replaces the coal—in one mine this condition continued for 200 meters. The coal is very tender, barely 10 per cent. of lump coal being obtained. It yields a remarkably good coke; the ash is from 7 to 16 per cent., but washing removes about half of it. It is no longer necessary to resort to washing, as mixing the dust coal of Szekul with that from the Liassic coal of Doman gives a coke without excessive ash.

Bohemia.

Coal has been found in a number of more or less widely separated areas within western Bohemia as well as in one within the southern portion. The general succession throughout is so nearly the same, that many students in later days conceive that the western areas are merely fragments of a once continuous field, intimately related to the Saxony basins at the north, and that there may have been a connection with the Silesian areas at the east. As Dannenberg has said, they are all limnic, as appears from the irregularity of the deposits, including the coal seams, which thicken and thin, often wedge out and abruptly change in character; the coal seams,

few in number, vary greatly; the deposits were laid down in deep troughs on Cambrian and Pre-Cambrian rocks and decrease toward the middle line of the trough. The unevenness of the surface explains absence of lower members at some localities. The succession is Coal Measures and Rothliegende and the passage from one to the other is so gradual that no boundary can be determined; the relation of Upper Carboniferous to Permian was in dispute for a long time and, even now, the matter seems to be undetermined at several localities. Katzer and others of the older workers divided the deposits into the Radnitz beds at the base, belonging to the Coal Measures, followed by a Middle Zone, with the Nürschan coal seam, and on top, the Kounovaer beds; the last two were thought to be Permian. Borings made in areas where exposures are rare, led v. Purkyne[34] to a different conclusion. The succession in a boring made where the Pilsen Basin is deepest and where exposures are rare, is, descending: (1) Upper red clay shales, red and variegated shale and sandstone, 155 meters; (2) upper gray clay shales, with gray to white sandstone and coal seams, 180 meters; (3) lower red clay shales, red and variegated shale and marly shale with arkose, 52 meters; (4) lower gray shale, gray shale and gray to white arkose, with at least 9 coal seams, 419 meters. He thinks that earlier students had failed to recognize the existence of two red deposits, for no borings had been made and exposures are very rare. The Lubna coal seam and the Nýran cannel are at the same horizon. Each of the coal-bearing divisions, composed of gray to black shale and gray to white sandstone, underlies a division of red shales and sandstones, barren of coal.

Weitkofer,[35] in a review of the northern basins, grouped the Permo-Carboniferous deposits into: (*d*) Upper red clay shale, Lihnaer beds; (*c*) dark gray clay shales, Schlaner beds, containing the Pilsen and Schlan coal seams; (*b*) lower red clay shales, Teinitzler beds, 190 meters, with no fossils aside from stems of *Araucarites;* (*a*) gray sandstone group, Kladno-Pilsener beds, 300 to 400 meters,

[34] C. R. v. Purkyné, "Zur Kenntnisse der geologische Verhältnisse der mittelböhmischen Steinkohlenbecken," *Verh. k. k. geol. Reichsan,* Jahrg. 1902, pp. 122–125.

[35] K. A. Weitkofer, "Geologische Skizze das Kladno-Rakonitzer Kohlenbecken," the same, pp. 399–420.

with the Kladno Hauptflötz at base. The Lubna and the Nürschan coals belong to the coal group in lowest part of the gray sandstone.

Dannenberg[36] states that the Lower Carboniferous and the Waldenburg (Sudetic or Schlesische stage) are wanting and that the series begins with the Saarbrück, to which he refers the Kladno-Pilsen sandstones as equivalent to the Schatzlar beds of Silesia; but the upper part of those beds are now regarded as belonging at the base of the Ottweiler and as equivalent to the Schwadowitz beds.

The Teinitzler beds (Hexenstein of Silesia) and the Schlaner (Radowenz) represent the Ottweiler, and the Lihnauer are regarded as undoubtedly Rothliegende. The Saarbrück consists chiefly of thick sandstones and conglomerates; the Ottweiler is mainly red shales and sandstones, but it has much gray shale and white sandstone. The Rothliegende (Lihnauer) has its characteristic flora. Deposition apparently was continuous throughout and at some localities the higher beds distinctly overlap the lower. The Lubna-Nürschan coal seam is proved to belong to the basal coal group not only by stratigraphical relations but also by the associated flora, which is Carboniferous.

The several basins from north to south are the Kladno-Schlan-Rakonitz, which is west from Prag and north from the Bersum River; the Pilsen and farther south the small areas of Radnitz, Miroschan and Merklin.

The Kladno-Rakonitz basin, extending southwestwardly from Kralup to beyond Rakonitz, has a gross area of not far from 450 square miles (1,100 to 1,200 square kilometers), but the productive area is very much less. The stratigraphy is simple as it is not obscured by disturbance, the dip rarely exceeding 6°, except on the extreme border, where it becomes at times 15° or 20°. The largest coal seam, known as Grundflötz or deep Radnitz, is at the base, often separated by only a thin deposit from the older rocks. Locally it becomes 6 meters thick, but ordinarily it is so dirty as to be worthless.

The Hauptflötz or Upper Radnitz seam, 3 to 18 meters above the Grundflötz, has been traced for 60 meters along the strike and has been followed for 4 kilometers along the dip. It is extremely

[36] A. Dannenberg, "Geologie der Steinkohlenlager," pp. 232–257.

irregular. At both extremities of the basin it is too thin to be worked, but in two sub-districts, near Kladno at the north and Rakonitz at the southwest, it becomes workable; but even in these the variability is serious; a strip without available coal divides the Kladno district. In that district, the Hauptflötz at times rests directly on the older rocks, the Grundflötz being absent. It is in three benches with 3.75 to 5 meters of partings. In the eastern part of the district, the middle and lower benches are practically worthless, the ash being 26 to 28 per cent.; in the western portion the seam, 12 to 18 meters above the thick but worthless Grundflötz, is still triple, but the partings have become thin, so the whole mass, 9 to 12 meters thick, is mined as a single bed. In the Rakonitz area, the Hauptflötz occasionally has 4 to 5 meters of coal, but, especially toward the west, it tends to break up, so that there are few localities where it can be mined. Coal in the northern part of this basin is maigre and dirty, but near Kladno, it becomes fatter and at times less dirty: ash varies from 1 to 30 per cent.; caking coal is rare and cannel occurs at some localities.

Near Lubna, beyond Rakonitz, is the Lubna seam, of which Katzer[37] has given the section, which, descending, is: (1) Compact coal, in part brown, 0.30 to 1.10; (2) black clay parting, 0.03 to 0.20; (3) black cubical coal, 0.20 to 0.30; (4) compact brownish cannel with *Stigmaria,* 0.20 to 0.25; (5) thinly laminated Brandschiefer, with remains of ferns, 0.10 to 0.20; (6) clay with sphærosiderite, 0.20 to 0.50; (7) hard Brandschiefer, with remains of plants, 0.10 to 0.20.

The accepted reference of this seam, at the time when Katzer's work was published, was to the Permian, but later studies have proved that its place is in the basal portion of the Saarbrück and that the associated flora is Carboniferous, not Rothliegende. The presence of abundant *Stigmaria* in the cannel is worth noting. The same form abounds in a clay parting near Rakonitz.

The higher coal group, in upper part of the Schlaner beds, is separated from the lower group by the great mass of the Kladno-Pilsen sandstones, the Teinitzler beds and the lower portion of the

[37] F. Katzer, "Geologie von Böhmen," 2te Aufl., Prag, 1902, pp. 1118, 1158.

Schlaner beds, not less than 600 meters of rock. It is but a short distance below the Lihnaer red beds, belonging to the Rothliegende or lower Permian. Dannenberg calls this upper group "modest"; usually there are two coal seams, the upper, 0.5 to 1.04 meter and the lower, 0.3 to 0.4 meter thick, parting included in each case. Near Schlan, these seams are separated by an interval of 8 meters but, toward the west, they approach and finally become one seam, 0.4 to 1.7 meter thick. The coal is rich in volatile and contains about 14 per cent. of ash. The floor is a bed of sphærosiderite, with finely preserved plant remains. The roof is a Brandschiefer, termed "Schwarte," which approaches gas coal in composition but has no practical value. It has yielded a rich harvest of crustaceans, fish and *Stegocephalus.*

Lipold,[38] who believed that the Schlaner beds are Permian, has given the section of this bed as exposed near Schlan; it is:

(1) "Schwarte," 8 inches; (2) coal, 1 foot 8 inches; (3) clay, 3 inches; (4) coal, 1 foot 8 inches; (5) clay, not measured. This "Schwarte" is tender, black-brown Brandschiefer, so rich in bitumen that it ignites readily. Lipold asserts that it distinguishes Permian coal from that of the Coal Measures.

There are comparatively few exposures in the middle of the basin; borings, reported by Katzer,[39] show that the upper coal group is present on the western side. The borings begin in Rothliegende; the first reached biotite granite at 74.5 meters, that being the country rock. A coal seam, 0.49 meter, was pierced at 71.8 meters. In another boring, a seam of "Schwarte" and coal, 1.06 meter, was pierced at 89.59 meters from the surface, and was identified with that of the first boring. It underlies a clay shale and rests on dark clay shale, containing streaks of coal. An argillaceous sandstone at 17 meters from the surface contains fragments of *Araucarites* and appears to be in the undoubted Rothliegende. The boring ended at 23 meters below the coal seam, but did not reach the gran-

[38] M. V. Lipold, "Das Steinkohlengebiet in nordwestlichen Theile der Prager Kreises in Böhmen," *Jahrb. k. k. geol. Reichsan.*, Band XII., 1861–2, pp. 507–509.

[39] F. Katzer, "Zur Kenntniss der Permschichten der Rakonitzer Steinkohlenablagerung," *Verh. k. k. geol. Reichsan.*, Jahrg., 1904, pp. 291–293.

ite; evidently the old surface was irregular and the overlap is notable, for only the highest part of the Schlaner beds is present.

The Pilsen Basin, not more than 30 miles south from Rakonitz and at extreme western extremity of the larger area has a total extent of not far from 150 square miles; the succession is practically the same as in the basin at the north, but the strata have endured much greater disturbance. Dips on the border reach 55°, though in the interior they sometimes become insignificant. The lower or Radnitz group shows 3 coal seams, known locally as the Fürstenflötz, Oberflötz and Unterflötz, the second and third being equivalent to the Hauptflötz and Grundflötz of the Kladno-Rakonitz region, while the highest seam is the same with that at Lubna near Rakonitz.

The variations in interval-thicknesses within this petty area are as remarkable as those proved by actual mining within the Anthracite fields on Pennsylvania. Dannenberg gives these measurements for opposite sides of the basin, separated by not more than 10 or 12 miles:

	Eastern Side.	Western Side.
1. Upper coal group.		
2. Interval	200	
3. Fürstenflötz	0.32 to worthless	0.5 to 1.15
4. Interval	15 to 132	17
5. Oberflötz	1.1 to 2.1	1.0 to 2.0
6. Interval	45 to 70	18
7. Unterflötz	1.8 to 4.4	0.5 to 1.0

The surface of the underlying rock is uneven, so that the Unterflötz is often wanting. The important seam is the Hauptflötz, which is usually 1 to 2 meters thick, but toward the north, occasionally swells to 3 or even 5 meters. The highest or Fürstenflötz is available midways in the basin, where it is known as the Nürschan cannel. Katzer[40] placed this in his "Middle Zone" and believed it to be lower Permian. He has given a detailed section of the bed as seen at Nürschan: (1) cubical black coal, 0.30; (2) black clay, 0.03 to 0.30; (3) cubical black coal, 0.30; (4) cannel, rich in *Stigmaria,* a few ferns, some bones; (5) Brandschiefer, thinly laminated, remains of ferns, some saurians and fishes, 0.25; (6) Platterkohle, in thick slabs, the chief source of saurian remains, with streaks of clay,

[40] F. Katzer, "Geologie von Böhmen," p. 1148.

0.30; (7) blattering [coarse] coal containing *Calamites,* replaced with pyrite, 0.08.

This section certainly bears close resemblance to that of the Lubna seam. The "gas coal" is usually shaly in structure but it passes into true cannel. It is clearly a lens as the thickness varies from a few centimeters to more than a meter. The Brandschiefer contains the remarkable Nürschaner fauna described by Fritsch and thought by him to be Permian, though its species differ from those of the higher deposit. The flora above it would seem to indicate an earlier age as it is very closely related to the Upper Carboniferous. According to Dannenberg, coal like that of Nürschan occurs occasionally, but locally, in the Unterflötz. The upper coal group, in the Schlaner beds, is unimportant; it contains two coal seams, but these are "workable" in only limited areas.

The Radnitz Basin, west from that of Pilsen, is very small and preserves only the Kladno-Pilsner beds which have an average thickness of about 100 meters; the succession is Barren sandstone, at most, 30 meters; shale with two coal seams, 40 to 45 meters; sandstone and conglomerate, very thin at times but occasionally reaching 60 meters. The Unterflötz is about 4 meters thick, but partings make the coal dirty; the few good layers are replaced with rock toward the middle of the basin. The Hauptflötz is 10 to 11 meters thick in the southern part of the basin. It is triple, but the middle bench alone is persistent; the lower is often replaced with rock and the upper thins away toward the northeast.

A petty area of anthracite coal is present near Budweis in southern Bohemia; it was studied by Katzer[41] soon after resumption of mining operations in 1890 and his results were published several years later. The exposed area of the deposits, believed by Katzer to be Permian, is barely 6 square miles. At the east and west the underlying rocks are Archean; at the north and the southwest, Tertiary beds overlie the Permian. There are two divisions; the lower consists essentially of conglomerate, sandstone and arkose; the upper has at base the coal group on which rest prevailingly red beds.

[41] F. Katzer, "Die Anthracit führende Permablagerung bei Budweis in Böhmen," *Oesterr. Zeitsch. f. Berg- und Hutt.,* Jahrg XLIII., 1895, sep. pp. 1–26.

The upper deposits show none of the regularity characterizing those of the lower division. The coal group consists of dark gray to almost black shale and sandstone, with thickness of not more than 20 meters. The seam of anthracite is from 80 to 120 centimeters thick; the dip at the important mine is toward north-northwest at abut 30° and there is little variation in thickness. The coal is clean anthracite throughout, except locally, where a thin black parting with some pyrite is found. The volatile varies from 6.2 to 6.8 per cent. and the ash from 6.4 to 9.4; complete analysis gives carbon, 88.90; hydrogen, 2.91; oxygen and nitrogen, 2.10; sulphur, 1.49; water, 1.80; ash, 2.80.

Dips vary from 1 to 45° and the whole district is much broken by faulting.

Germany.

Saxony.—The coal basins of Saxony, in the southern part of the kingdom are small, but the seams are often thick, yield good coal and are of great economic importance. The Zwickau and Lugau areas, known as the Erzgebirge basins, are at the southwest and the Döhlen (Plauenschen Grundes) is at a few miles away toward the norheast. Coal has been mined in some localities for centuries and the region has been studied by many geologists.[42]

The petty basins of Hainichen and Ebersdorf on northeastern border of the Carboniferous region hold deposits of Culm age. The lower division or Grundconglomerate has maximum thickness of 2,000 feet, but this decreases rapidly toward the south until the whole Culm is barely 1,700 feet, of which not more than one half belongs to the lower division. The coal-bearing or upper division, consisting mostly of sandstone, has four thin seams, which have been

[42] The works examined are H. B. Geinitz, "Die Steinkohlen Deutschlands und anderer Länder Europa's," Band I., 1865, pp. 45–90; H. Mietzsch, "Geologie der Kohlenlager," 1875, pp. 150–156; "Erlauterungen, etc., Blatt III., 1877; Th. Siegert, "Erlauterungen, etc., Th. Siegert, "Erlauterungen, etc., Das Steinkohlen-revier in Lugau-Oelsnitz," 1882; J. T. Sterzel, "Erlauterungen, etc., Section Stellberg-Lugau, Blatt 113"; "Palaeontologische Character des Steinkohlenformation und das Rothliegende von Zwickau," 2te Aufl., 1901; R. Hausse, "Steinkohlenbecken der Plauenschen Grundes (Döhlener Becken)," 1892; A. Dannenberg, "Geologie der Steinkohlenlager," Band I., 1908, pp. 199–224.

mined for local use. The coal is low in volatile and is said to be an excellent fuel.

The Coal Measures occupy depressions in gneiss, crystalline schists or in the older paleozoic rocks. The surface on which they were laid down was irregular and Lower Carboniferous is not always present. Within the Zwickau and Lugau areas, one finds the Saarbrück and the Lower Ottweiler, the Upper Ottweiler, if ever present, having been removed by erosion prior to deposition of the Rothliegende, which rest discordantly upon the Coal Measures. It is not easy to determine the boundary between Saarbrück and Ottweiler; Geinitz recognized three zones, marked by *Sigillaria, Calamites,* Ferns; later students, however, preferred to make only two, *Sigillaria* and Ferns, placing the limit about midway in the *Calamites* zone.

The Zwickau area is very small, not more than 20 square miles, but its coal seams are numerous and often very thick. These display in full all the peculiarities of limnic beds, variations in thickness, tendency to divide and to subdivide, frequent passage into shale and even into sandstone. The lowest persistent seam is the Planitz, which, at the southwest is practically single, but toward the northeast it is divided by increasing interval rocks and the three main benches become three seams, *A, B, C,* each of which has more than one local name. Near Planitz, the thickness is about 10 meters, the interval between *A* and *B* being less than half a meter; nearer Zwickau, the intervals are a half meter and two and a half; but, farther north, they become 40 and 15 to 30 meters respectively, the coal being 2, 4 and 4 meters in the several seams. The interval rocks are mostly sandstone. Toward the east and south, these seams are broken by so many partings as to be worthless, though they contain much good coal. In great part, the coal is bright Pechkohle, but it is often laminated or Schierferkohle and at times it passes into Russkohle, in which fusain (Faserkohle or Mineral Charcoal) predominates. The great Russkohlenflötz, at 40 to 56 meters above the Planitz, has an extreme thickness of 8 to 9 meters, almost wholly clean Russkohle. Toward the east and north, it breaks up into at least three seams, in which the Russkohle is often replaced with ordinary laminated coal. The coals of this lower

division, aside from the Russkohle portions, are, according to Mietzsch, coking. Geinitz states that the Planitz coal is of *Sigillaria* origin, while that of the Russkohlenflötz is derived from *Calamites*.

The higher zone has 7 seams of workable gas coal, 5 of which, one to three meters thick and yielding a caking gas coal, are practically exhausted. At best, their area was insignificant. The lowest two seams, Zach- and Schichtenkohlenflötz, are in larger area and each has a maximum thickness of somewhat more than 5 meters. Like the other seams, these divide and subdivide, the former toward the west and the latter toward the east. The total thickness of Coal Measures in the Erzebirge basins averages not far from 400 meters; that of the lower division, according to Mietzsch, varies from 40 meters in the southwestern portion to 80 and even 150 meters in the northeast, owing to inlaying of sandstones and conglomerates. The Rothliegende in these basins contains some worthless streaks of coal in the lower part.

The Döhlen basin or Becken des Plauenschen Grundes contains workable coal of Permian age, as determined in 1849 by Geinitz and Gutbier. Murchison[43] found the whole thickness of Lower and Middle Rothliegende between 800 and 900 feet. The conglomerates of the lower portion are gray, with blocks of granite, quartz and even of Coal Measures rocks. The coals are from Permian plants. These deposits, occupying a depression in Silurian rocks, consist of sandstones, conglomerates and shales, with, in the northern portion, a porphyry flow at the base. The color is mostly gray but variegated shale is present in the basal portion of the Middle Rothliegende. The coal seams are about midway in the Lower Rothliegende, within a mass of gray shale and sandstone, 20 to 30 meters thick. Geinitz mentioned four seams, of which the lower two are very thin. The third occasionally is thick but, for the most part, its coal is so dirty as to be almost worthless. The fourth or Hauptflötz is from 1 to 7 meters thick, the greatest thickness, as Hausse has shown, being in the deeper part of the basin; toward the border it becomes thin and impure. The partings are thin, but some of them are remarkably persistent. The coal is mostly laminated, but it often passes into Brandschiefer. The ash content is high, being,

[43] R. I. Murchison, "Siluria," 3d ed., 1859, p. 345.

according to Dannenberg, 18 to 32 per cent., selected specimens having as much as 22 per cent. The water is from 4 to 8 per cent. A thin coal seam is present in the basal portion of the Middle Rothliegende, but is without value.

In all areas, the Rothliegende is unconformable to the Coal Measures. Fragments of Coal Measures rocks are common in the basal conglomerate and Siegert saw in the Lugau area large blocks of coal torn from exposed coal seams. Grains of coal occur commonly.

In 1881, Sterzel discussed the origin of coal seams and in 1901 a revised edition of his paper was published. He sums up in thoroughly judicial manner the features which, for him, appear to suggest autochthonous origin of the materials, and then presents the features which indicate allochthonous origin. These are:

(*a*) The often very distinct lamination of the coal; (*b*) the Bergmittel, which at times occurs abundantly within coal seams and consists of the same rock material as the Hangende and Liegende of the seam, is evidence of quiet deposition, as must be accepted for the plant material itself. Bergmittel may be in form of increased ash in the coal, or as conformable deposits, plates or benches of clay shale, or iron ore, varying in extent and often splitting the coal bed into an extraordinary number of thin plates. A new vegetation for each of these many thin coal layers appears inadmissable; (*c*) Stigmaria occurs frequently in the roof; (*d*) vertical stems in the roof of beds are only local and occasional. He concludes that the majority of facts speak for allochthonous origin of the Zwickau coal seams.

All observations lead him to the belief that the coal seams were formed in a lake basin, into which the plant material was carried from the widely extending swampy surrounding land, which was fitted for Waldmoors with luxuriant vegetation, as well as from the higher slopes, on which were plants, loving a drier region. The infloating was done by quiet waters, which carried very little inorganic matter. Plant materials predominated, so that great masses of more or less rotted organic matter were heaped up on the lake bottom, where afterward they were converted into coal. Occasionally, the watercourses were swollen and brought down rock material, which

formed partings, to be covered in succeeding time of quiet by a new deposit of plant stuff.

Periodically, perhaps because of crustal movements, notable changes came about in the fall of streams, leading to violent floodings. Then rock materials predominated and deposits of sand, mud and pebbles were formed, covering the plant materials, which are now the coal beds. Later came the period of quiet and the Waldmoor expanded to its former luxuriance. During the interval, many species of plants had been destroyed while others survived and new forms appeared. This doctrine of local change does not exclude changes in the lake bottom; that might be brought to a higher level, so that growth of plants might begin on it. Increased accumulation of detrital material in the lake would have the same effect. Perhaps, in some places of this sort, there grew the vertical stems, giving a local autochthonous formation.

Sterzel's conception closely resembles that presented by Grand'Eury in 1882, which was abandoned by that observer after his knowledge had been increased by careful studies in regions aside from his own basin of St. Etienne. But the presentation is far from being conclusive.

Lamination of coal is by no means evidence that the material was transported; autochthonous peat, subjected to pressure, has the same structure. *Sigillaria* and *Lepidodendron* occur in roofs of coal seams; as *Stigmaria* is the rhizome of those plants, it ought to occur in roofs. Partings, such as those of coal seams, are familiar features of autochthonous peat deposits. Vertical stems are apparently rare and local in roofs, but there are vast areas of growing peat without trees, while there are other areas in which the Waldmoor condition prevails. It must not be forgotten that our knowledge of roofs is confined chiefly to exposures in mines, where the stems are only too abundant.

There is not much basis for the suggestion that a great lowland area, covered with Waldmoor, was the region surrounding the Zwickau lake. The Erzgebirge had been elevated prior to Carboniferous time and the Zwickau basin is at the foot of those mountains. Even if there had been a great Waldmoor area, it is inconceivable that streams meandering across it could bring down such great quan-

tities of macerated vegetable material. The density of vegetation in a Carboniferous Waldmoor was not inferior to that of a tropical jungle. Rain would have practically no erect on even loose plant stuff, while the meandering streams would remove little from their banks. Every one knows that such streams have great plumes of confervæ swinging from the banks, undisturbed year after year. It is difficult to conceive of crustal movements so abrupt as to cause floods, so sudden and severe as to sweep débris over the plain, to destroy the great Waldmoor and to leave no trace of the dense vegetation in the newly deposited rocks. It is equally difficult to understand why crustal movements should increase the water-supply. They would lead to rapid draining of the region but could not bring about terrific floods unless the rainfall were increased many times. In any event the floods would be mere floods, not devastating torrents, unless the Waldmoor area itself were distorted, in which case it would not be available for a new Waldmoor.

In 1903,[44] Sterzel described a *Sigillaria* stump, seen in the roof of the Zachkohenflötz. It was 1.25 meter high and tapered from 1.15 at base to 0.50 meter at top. The base was completely plane and the border was sharp. There is no trace of branching or of *Stigmaria,* as there should be if the plant were in place of growth. The stem evidently had been torn from its place by muddy water, robbed of its basal branching and then deposited in the roof of the coal seam. The softened base had become flattened under pressure. He states that the limit between coal and roof is "haarscharf" and that nowhere does the plant rise out of the coal into the roof. Sterzel's description shows that here is the familiar "Sargdeckel." The region is disturbed, the contact between coal and roof is sharp, neither is in its original relation to the other. The faulting explains the smooth base of the stump. Such stumps are not rare in roofs of the Zachflötz and Segen-Gottesflötz of Zwickau area.

Sterzel,[45] in a later paper, described a petrified forest observed in the Rothliegende of the Chemnitz region. The rich locality, near

[44] J. T. Sterzel, "Mitteilungen aus der Naturwiss.-Samlung der Stadt-Chemnitz," *Ber. Naturwiss. Gesells. Chemnitz,* t. XV., 1903, Separate.

[45] "Der versteinerte Wald," etc., the same, Band XVIII., 1913, Separate, p. 52.

Neuhilbersdorf, embraces about a square kilometer. The ground is full of petrified trees; beside prostrate, always fractured stems, large and small stems are seen as vertical stumps, apparently in the original place of growth. Silicified stems are shown at several places near Chemnitz. They are embedded in the marly beds of the Middle Rothliegende, on which, apparently, they grew.

He cannot accept the opinion that the trees while living were enveloped suddenly by the falling tuff and that they were silicified afterward. The plants are without bark and are broken across the stems. He believes that silification began during life of the trees and that it caused their death. The microscopic structure is as perfect as in living plants. All are conifers—*Araucarioxylon,* to which the leaves and twigs of *Walchia* seem to belong. Stems, 7, 10 and 20 meters long, are in the Chemnitz museum.

Thuringer Wald.—The Permian contains coal seams of workable thickness at several localities in Germany. For the most part, they have little interest, but the conditions in the Thuringian forest should be noticed. This area, bordering on Bavaria at the south, was visited several times by Murchison,[46] who states that in some valleys on each side of the Central Range there occur occasional outcrops of gray and dark colored shaly rocks, containing plant remains and at times seams of coal. These he regarded as belonging to the Upper Coal Measures of Germany. The coal is most abundant at the southerly end of the area, where it has been reached by shafts, which pass through a great thickness of Rothliegende. These Carboniferous beds were formed, he believes, during tranquil deposition, in marked contrast with the Permian beds, which were laid down during a time of great disturbance, marked by extrusion of much igneous material and by powerful translation of broken materials from preëxisting rocks. The coal-bearing deposits pass under cover toward the north.

Beyschlag,[47] writing many years afterward, stated that study of the central portion of the region is difficult as no good section is exposed. Eruptive rocks are abundant and sedimentary rocks

[46] R. I. Murchison, "Siluria," 3d ed., 1859, p. 332.

[47] Beyschlag, "Geologische Uebersichkarte des Thuringer Walden," *Zeitschr. d. d. Geol. Gesells,* Band 47, 1895, pp.. 596–607.

change abruptly in character as well as in thickness. Conglomerates prevail at the southeast, but in the middle and northwest portions the rocks are chiefly sandstones and shales. He assigns the whole section to Rothliegende, there being no Upper Coal Measures in the region. The succession is:

Upper	Tambacher beds	
Middle	Oberhofer beds	Lebacher beds
	Goldbauter beds	
Lower	Mansbacher beds	Cuseler beds
	Gehrener beds	

The Gehrener beds contain much eruptive matter and arkose; red and black shale with gray sandstone and breccia prevail; coal smuts and seams were seen near Gehren and a few other localities. The Mansbacher beds have no eruptives, the rocks being sandstone and clay shale with some thin seams of coal. At one time, six of these seams were mined. The flora of these shales was supposed to be that of the Upper Ottweiler (Stephanien), but it is predominantly Rothliegende, though containing many Ottweiler forms. *Walchia* occurs in sandy clay shale but never in the softer, plant-rich shales. The Goldbauter beds have much eruptive material in the western portion but none in the eastern. Midway in the section is a thin seam of coal. This is the highest, there being no coal in the Oberhofer or Tambacher beds.

Dannenberg[48] cites v. Dechen as stating that coal occurs in the Middle and Lower Rothliegende. The important locality is on the Bavarian border near Stockheim and Neuhaus, where a seam, 2.90 to 29 meters thick, is mined. When very thick, the coal is notably dirty, but washing removes most of the impurities and the coal, thus treated, is an excellent fuel. The output of washed coal in 1911 was 50,000 tons and plans were under way to increase it to 240,000.

The Pfalz-Saarbrück-Lorraine Coal Field.—This, known as the Saarbrück basin, is comparatively insignificant in area but is amazingly rich in the number and availability of its coal seams. The space, in which seams are exposed or under reasonably thin cover, is

[48] Geologie der Steinkohlenlager, p. 229.

rudely triangular, about 20 kilometers wide on the Saar River and diminishing northeastwardly to 10 kilometers at a little way beyond Neukirchen, 50 kilometers from the Saar. The extreme distance, along which the coal is accessible, is barely 100 kilometers, extending from beyond the eastern border of Lorraine across the narrow strip of Prussia into the Rheinpfalz of Bavaria. The field has been described more or less in detail by many students, but use will be made here only of works by Nasse,[49] v. Ammon and Dannenberg. Nasse and Dannenberg have discussed the whole basin, while v. Ammon has described in detail the Bavarian field, which embraces the greater part of the available area.

The deposits occupy a trough, much distorted, which is cut off abruptly at the south by the südliche Hauptsprung, a downthrow of not less than 1,000 meters. Only Permian and Carboniferous rocks have been found within the trough, but Bunter Sandstein is present just beyond the immediate area. The lowest beds reached by borings are Saarbrückian, which are succeeded by Ottweiler and Rothliegende in conformable order, so that the whole may be termed the Permo-Carboniferous system; but in the extreme western portion, within France, there is unconformity, for there Rothliegende rests on disturbed Saarbrückian beds. The latest classification is Rothliegende, Upper, in four divisions, of which the Lebacher beds are the lowest. This contains plants, Estheria, reptiles, fishes and worthless streaks of coal. Lower, the Kuseler beds, containing similar fossils, some calcareous beds and streaks of coal.

Upper Carboniferous,

Ottweiler beds. Upper, containing fish remains, etc., with Breitenbach coal bed. Middle, or Potzburg beds, with some calcareous beds, *Leaia, Cardinia* and the Hirteler coal seams. Lower, the Hangende Flötzzug, fossils as in Middle; Holzer Conglomerate at base.

Saarbrück beds. Upper or Flammekohlen Gruppe, Lower or Fettkohlen Gruppe.

[49] R. Nasse, "Geologische Skizze des Saarbrücker Steinkohlengebirge," *Zeitsch. Berg-hutten-Salinen-wesen im Preuss.*, Band 32, 1884, Abh., pp. 1–89; L. v. Ammon, "Die Steinkohlenformation in den Bayerischen Rheinfalz," München, 1903, pp. 1–106; A. Dannenberg, "Geologie der Steinkohlenlager," pp. 105–165.

Lower deposits are unknown and it is uncertain whether or not the Waldenberg (Sudetic, Lower Westphalian) and Lower Carboniferous are present. The rocks are of limnic origin; no marine forms have been observed.

Dannenberg gives the thickness of Rothliegende as not less than 2,000 meters, that of Ottweiler as 1,500 to 2,000 and of Saarbrück as 2,500 to 3,000 meters. Nasse estimated that Ottweiler is 1,700 to 2,000 in the area between Saar and Blies Rivers, but 3,000 in the eastern portion within Bavaria; the Saarbrück, on the contrary, become thinner toward the east, being 3,200 on the Saar but only 2,100 on the Nahe River. Borings in later years have proved that, while it is true that Ottweiler increases notably toward the east and that Saarbrück decreases notably in that direction, the variations are not so great as Nasse believed. It is very clear that influx of material for Saarbrück was from the west and for Ottweiler from the east, the coarse deposits for the latter being on the east side, while in the former they are on the west side.

The number of coal seams, according to Dannenberg, is not far from 400, of which 150 to 160 are workable, that is to say, are more than half a meter thick. Nasse showed that these are grouped into "Flötzzuge," separated by practically barren intervals. The coal seams of the Rothliegende and Ottweiler are not important and only insignificant seams were formed above the Kuseler beds. There were serious extrusions of igneous rocks in the earlier Saarbrück and in the closing portion of the Upper Rothliegende.

Thin coal is present in the Lebacher beds, which are mostly yellow sandstone and dark shales; in the western portion, the shales have fish remains and iron ore, but the ore is wanting at the east. The flora, according to Nasse, consists almost wholly of Rothliegende forms, with very few of Coal Measures type. The Upper Kuseler rocks are mostly gray shales and sandstones; coal seams were observed at many places; one, the Kalk-kohlen Flötz, has a limestone roof and occasionally becomes 47 centimeters thick; another, near the base, the Muschel-kohlen Flötz, is from 15 to 20 centimeters thick and its shale roof has abundant *Anthracosia*. The Lower Kuseler consists chiefly of gray and red sandstones, variegated shale and thin layers of limestone. Fish remains have been

obtained at several horizons and the flora is rich in Rothliegende forms, among them, *Callipteris conferta*. With these are many Coal Measures species, but no *Sigillaria* or *Stigmaria*.

The Upper Ottweiler, about 125 meters thick, has mostly grayish deposits, laminated shales and micaceous sandstones. In Bavaria, it has the Breitenbacher or Hausbrandflötz, 12 to 30 centimeters thick, which is mined by stripping at many places, as the coal is an excellent domestic fuel, being maigre, smokeless and without clinker. The flora is mingled Saarbrück and Rothliegende; Weiss, quoted by v. Ammon, has described it as a "prevailingly stone-coal flora; *Stigmaria, Sigillaria* and *Lomatophloios* still abundant, ferns numerous, *Walchia* rare." Animal remains are few, chiefly insects and crustaceans. The Middle Ottweiler is a thick complex of mostly red sandstone and conglomerate, with red, bluish and yellow shales. The conglomerates, according to Nasse, are not constant but are lenses. The Hirteler coal seams are unknown in Bavaria but are present near Saarbrück in Prussia. Fossil plants are not abundant and such as do occur are indefinite, but silicified wood is not rare. v. Ammon states that the mass is 800 meters thick near Saarbrück, but near Dudweiler in Bavaria it is 950. The Lower Ottweiler, formerly regarded as Upper Saarbrück, about 800 meters in western part of the basin, contains much red rock, gray, reddish and greenish shades and sandstones. Its base is the Holzer conglomerate, which is characteristic at the east but becomes insignificant toward the west. Over it are the *Leaia* shales, which enclose thin layers of limestone and underlie the Hangenden Flötzug, consisting of gray and some red sandstone and shale with two or three variable seams of coal. The thicker seams, Lummerschieder and Walschieder, are of workable thickness in the Prussian area but become insignificant or disappear toward the east in Bavaria. At Frankenholz, 5 coal streaks were found but at Dittweiler, farther east, no trace of coal was found in the boring. The thickness in the Prussian area is not far from 1,000 meters and is considerably more in Bavaria.

The Saarbrück is divided into the Upper or Flammekohlengruppe, yielding a sintering coal, and the Lower or Fettkohlengruppe, from which coking coal is obtained. Conglomerates are numerous, especially in the western portion, where, according to

Nasse, there are beds more than 40 meters thick. The pebbles are mostly of quartz but other rocks are represented. The shales are gray to blackish, but some beds are red or green. The flora, according to Weiss, cited by v. Ammon, is a "Steinkohlen flora, with many *Sigillaria* and lycopods as well as ferns." v. Ammon states that *Walchia pinniformis,* characteristic of the Lower Rothliegende, occurs sporadically. The Schatzler beds of the Lower Silesian basin have a flora like that of the Lower Saarbrück.

Within Bavaria, the Upper Saarbrück coals are mined at Frankenholz and Consolidated Nordfeld, both in the eastern portion. The group is divided into Upper and Lower, the former being worked at places named. Twenty-five coal seams have been discovered, of which more than half yield a gas coal while the others have Flammekohle. The screenings of each are mixed with Fettkohle in manufacture of coke. The seams show great variation within Bavaria; several, which are important at some localities, become unworkable or disappear within short distances. The seams become thicker toward the west. Kliver, cited by Dannenberg, states that at or near Jaegersfreude there are 10 workable seams, 21 which are too thin for working under present conditions and 101 which are mere streaks; in all, 132 with 32 to 33 meters of coal. Some seams are from 3 to 5 meters thick, but they are broken by partings into several benches. The lower division is less important, having only 3 or 4 workable seams, though the whole number of seams is about 40. At one time it was believed that this division thinned away toward the east, but this opinion has not been confirmed by the later observations.

The Lower Saarbrück or Fettkohlenpartie yields coking and gas coals. The number of seams and the coal content increase from east to west. This division is mined in the Pfalz region within the St. Ingbert and Mittelbexbach areas, where three groups of coal seams exist. The upper, about 537 meters thick, has 40 seams; a barren space of 63 meters separates it from the middle or Rothhell, 240 meters thick and containing 19 seams; at probably 300 meters lower is the bottom group, discovered in a boring within the Rischbach Valley, which has 12 thin seams. The rocks of Lower Saarbrück are coarse, there being much sandstone and conglomerate.

The coals of the highest group vary from Fettkohle to Flammekohle; a single seam may yield both kinds. The Rothhell consists of gray shales, hard sandstones and conglomerates with an occasional red bed. The coals are important at St. Ingebert, but westwardly they decrease and are insignificant at the Saar River. The Rischbach seams appear to be merely local, having been found only in a boring and a shaft within the Rischbach Valley.

In the Mittelbexbach area, 10 seams with 9 meters of coal are mined. They belong to the highest group and yield only Flammekohle, which is an admirable domestic fuel. The mines are near the südliche Hauptsprung, where the strata are seriously disturbed. The seam, Number 3, has an interesting structure in one mine. It consists of coal, 0.04; parting, 0.20; coal, 1.20. The thin bench on top is much broken by overthrust faults, which involve the parting, but the main coal is practically undisturbed. This upper group of the Lower Saarbrück becomes extremely important in the vicinity of Saar River, where there are 40 workable seams with 50 to 60 meters of coal. Cannel is present occasionally but it is unimportant. At one place it is the highest bench; at another it is the lowest.

Nasse, in discussing the character of coal seams, states that in this basin a seam one meter thick is rarely without partings, but he mentions one, 4.08 meters, which yields clean coal throughout. Variation in thickness is the rule; mere streaks become important seams, which may thin away to disappearance. The intervals are uncertain, so that seams widely separated at one locality may be united at another. Very often the roof is Brandschiefer, a coaly shale, which is combustible. When sandstone or conglomerate is the roof, the upper part of the seam is irregular; but the bottom rarely shares in this irregularity.

The Ruhr Basin.—Several coal basins are in northwestern Prussia, which are of moderate extent but, in some cases, economically important. The Ruhr, Lower Rhine or Westphalian basin lies east from the Rhine along the Ruhr, Emscher and Lippe Rivers; the cities of Essen, Bochum and Dortmund are on the northern border. The area is not far from 3,200 square kilometers, but the thickness and quality of coal render it one of the most important on the continent. The outcropping portion is south from the cities mentioned,

but borings prove that the coals persist northward beyond the Lippe under increasing cover and that, in like manner, they are present west from the Rhine. The region has been studied carefully by Dannenberg,[50] who has supplemented his observations by those of other geologists.

The Lower Carboniferous (Dinantien) is shown on the eastern border, where it is succeeded by the Flötzleeren Sandstein (Namurien or Lower Westphalian), which apparently is without coal and is taken to be the equivalent of the Millstone Grit, the Sudetic of eastern areas. This is followed by the Productive Coal Measures, equivalent to Saarbrück (Upper Westphalian), as well as to the Lower and Middle Coal Measures of Great Britain. It is the important group. The Ottweiler, Stephanien of France, is apparently absent. Permian is represented almost wholly by the Zechstein, Rothliegende having been observed in only a few petty, isolated patches. The Saarbrück is in four divisions, which, in descending order, are:

	Volatile.	Chief Seam.	Thickness.
Gasflammekohlen	37–45	Bismarck	1,000 m.+
Gaskohlen	33–37	Catharina	290–300 m.
Fett- and Esskohlen	20–33	Sonnenschein	600–885 m.
Magerkohlen	5–20	Mausegatt	1,050 m.

There are variations in the conditions for, chemically, the coal of a seam is not the same throughout its extent. Beds of the Magerkohlengruppe at times yield coking coal; among the Fettkohlengruppe, some give gas coal while coking coal is obtained from several seams in the Gaskohlengruppe. Generally speaking, the volatile content increases from west toward east, as does the thickness of the seams. Conglomerate and ironstone are common in the Magerkohlen, less so in the middle divisions, but are abundant in the upper. Marine deposits are frequent in the lowest division, but become fewer above, where fresh-water fossils are the usual forms.

The Magerkohlengruppe is practically barren in the lower 250 to 300 meters, there being only thin seams, some of which are workable locally. The next portion, reaching to the Hauptflötz, has at

[50] A. Dannenberg, "Geologie der Steinkohlenlager," 1908, pp. 49–79.

least two workable seams and is 100 meters thick. The Hauptflötz and the Wasserbank, 80 meters lower, have well-marked marine roofs; between the Hauptflötz and the Mausegatt, 250 to 300 meters, coal seams are few and but locally workable; the Sarsbank, about midway, has a marine roof. The next interval, 100 to 150 meters, has four or five workable seams with 3 to 4 meters of coal and contains much iron ore, which was mined in earlier days. It has three beds with fresh-water fossils. The highest interval, about 300 meters, is almost barren, having few and rarely workable seams. The most notable feature is the rich marine roof of the seam Finefrau-Nebenbank near the base of the interval. This Gruppe ends with a well-marked conglomerate, 10 to 20 meters thick.

The Fettkohlengruppe, from the Sonnenschein to the Catharina, averages about 600 meters, but the mass increases toward the east, coal increasing in the same direction from 23.6 to 35.85 meters. Clay shales predominate, sandstone is rare and conglomerate is unknown. Ess- or Schmiedekohle, with about 20 per cent. of volatile, predominates in the lower part, but in the upper part the volatile becomes 33 per cent. and the coal is caking. The coal seams tend to divide, detracting from their value. Catharina alone is easily identified in a considerable area, as it has a marine roof.

Changes in most of the seams are so abrupt that tracing is impossible; mere smuts suddenly become workable seams and as suddenly become worthless again.

The Gaskohlenpartie is almost barren in the lower half, but the upper portion has about 10 workable seams with 8 meters of coal. The lower part has a seam of cannel, 47 centimeters thick. Changes in chemical composition of coal in individual seams are frequent. No marine forms have been discovered except at the very base, in the roof of Catharina.

The Gasflammekohlengruppe has 25 seams more than 50 centimeters thick. Clay shales predominate in the lower half and the coal seams are much less variable than those in the upper half, where sandstone and conglomerate prevail. Chemically, the coal varies notably; in extensive districts, only gas coal is found. Cannel occurs frequently; one seam has 1.36 m. as the upper bench and 1.37 m. as the lower.

There is every reason to believe that the Ruhr basin is continuous under cover with the Aachen basins at the west; it may be continuous also with the Limbourg area of Holland and the Campine area of Belgium, in both of which the coal is deeply buried and its existence has been proved by borings.

The Aachen Basins.—These, often referred to as the Westphalian basin, embrace, according to Dannenberg,[51] two areas, the Würm- (or Worm-) Revier, north from Aachen, separated by a strip of Upper Devonian from the Stollberg-Eschweiler Revier, southward from that city. The latter is known also as the Inde-Becken.

The Würmrevier, locality of oldest coal mining operations on the Continent, has not less than 45 coal seams in the western portion, of which 11 have been exhausted. Of the others, 14 are workable with 12.5 meters of coal, the lowest being the Steinknipp, about one meter thick. The disturbance in this portion was extreme and the coal is in great part anthracitic. Dannenberg notes that these coals are at horizons, which, in the Inde basin, have coals much richer in volatile. He suggests that the change was not due to disturbance alone but possibly in part to lack of thick cover. In the eastern portion, where disturbance, though severe, is less than in the western, one finds coking coal with 16 to 24 per cent. of volatile, and non-coking coal with 15 to 17 per cent. The remarkable horizon is the marine roof of Bed 6 at the Marie mine. The Flötzleeren Sandstein has not been recognized in this area.

The Inde-becken or Eschweiler revier has the succession complete from Lower Carboniferous to and including the Saarbrück. The boundary between Lower Corboniferous and Coal Measures is sharp, there being no passage beds between the limestone below and the sedimentary rocks above; yet there appears to be complete conformity. A mass, almost wholly sandstone and 800 to 1,000 meters thick, rests on the limestone. This, practically barren, as it contains only two or three unworkable seams of coal at 150 to 200 meters above the base, seems to be equivalent to the Millstone Grit. The Productive Coal Measures, somewhat thicker than the barren measures below, have two groups of coal seams, the Aussenwerke and

[51] A Dannenberg, "Geologie der Steinkohlenlager," pp. 83–101.

the Binnenwerke, separated by an almost barren interval of several hundred feet. The relations of the lower group, the Aussenwerke, cannot be determined satisfactorily owing to lack of distinct flora and fauna; it may be equivalent to the lower division of Würm, in which a marine deposit is roof of Marie number 6. But the Binnenwerke is unquestionably Saarbrückian or Upper Westphalian. Forty-five coal seams have been recognized, none of them thick. In the western portion of the workable seams, only 2 ever exceed 1 meter, 5 never exceed 75 centimeters and 9 are less than 60 centimeters. The Aussenwerke seams are thin.

The disturbance is much greater in the eastern part of this basin than in the western, but the coals are same, chemically, in both. Binnenwerke coals are caking and their coke is good, but that from the Aussenwerke is sintering. Five conglomerates are persistent; two of them, thick and coarse, are in the Flötzleere, above and below the coal seams; the third is just below the Aussenwerke and is an important stratigraphical horizon; the fourth is just above that division and the fifth, comparatively fine-grained, underlies the Padtkohl or lowest seam of the Binnenwerke.

Belgium and Northern France.

Some prongs of the Aachen Coal Measures reach into Belgium, but exposures end quickly and a space of about 20 kilometers, covered by later deposits, intervenes between the last Aachen outcrop and the first Belgian mines. Within Belgium, Coal Measures remain in the Dinant trough, at the south, but the basins are isolated, very small and without interest. At the north is the extensive Campine area, continuous with that of Limbourg in Holland, but that is known mainly through records of boring, as mining operations were begun very recently. Actual work is confined to the great Haine-Sambre-Meuse trough, which extends from the Prussian border across Belgium into the Department du Nord of France; it is interrupted only by a narrow barren space in the Samson Valley, which divides the Belgian area into the Liége basin at the east, including the Herve, Liége and Andenne districts, and the Hainaut basin at the west, embracing the Basse-Sambre, Charleroi, Centre and Couchant-de-Mons districts.

The succession in Belgium is sufficiently clear, though, owing to the extreme distortion along the southern border, some localities remain, in which relations are somewhat uncertain. The order as given by Renier is

Stephanien	Absent	
		Assise de Flénu (Renier)
		Petit-Buisson
Westphalien	Supérieur	Assise de Charleroi (Stainier)
		Gros-Pierre = Stenaye
		Assise de Chatelet (Stainier)
		Poudingue houiller
		Assise d'Andenne (Stainier)
	Inférieur	Veine aux Terres
		Assise de Chokier (d'Omalius)

Dinantien or Lower Carboniferous.

This is equivalent to the grouping presented by de Lapparent and Munier-Chalmas. Stainier prefers to limit the term Westphalien to the upper three assises and to apply the name Namurien to the lower part of the section. This nomenclature has been accepted by Dannenberg in his description of the Belgian fields. The coal seams, Petit-Buisson, Gros-Pierre and Veine-au-Terres are at or very near the base of the several assises. The number of marine horizons decreases upward; it has been suggested that some relation may exist between quality of coal and the origin of the rocks; Chokier, essentially marine, is wholly barren; Andenne has marine horizons and little coal, which is true also of Chatelet; but Charleroi, without positively marine deposits, is rich in coal; Flénu has but one marine deposit, that in roof of Petit-Buisson at the base, and this assise has much coal.[52]

Formerly, the Coal Measures were divided into H1, *a, b, c,* and H2, the former being the Namurien, the latter being the Westphalien or upper Westphalien. The general features of the lower division were described by Purves.[53] The Chokier, or basal assise, is a mass

[52] These details are mostly from A. Renier, "Les gisements houillers de la Belgique," *Ann. Mines de Belg.,* t. XVIII., 1913, pp. 757, 759, 767, 773.

[53] J. C. Purves, "Sur le delimination, etc., de l'étage houiller inférieur de la Belgique," *Bull. Acad. Roy. Belg.,* III., t. II., 1881, sep., pp. 1–57.

of shale, 10 to 70 meters thick, increasing toward the west. The middle portion, the Andenne of Stainier, is 130 to 400 meters, increasing, as the Chokier, toward the west. It has thin streaks of terroulle or earthy coal, one of which, near the base, has been mined; it has a sandstone roof containing *Calamites* and is 40 centimeters thick; it has a true underclay, with *Stigmaria.* A persistent band of ripple-marked sandstone, 5 to 10 meters thick, overlies the coal-bearing shales and a marine deposit is near the top of this division. The Grés grossier, or Poudingue houiller, the Poudingue de Monceau-sur-Sambre of Mourlon,[54] at top of the Namurien, 12 or more meters thick, varies from fine sand to coarse conglomerate.

Dannenberg says[55] that in the Liége district the Andenne has three seams, of which the middle one, V. au Gres, is the best; that at the base, V. aux Terres, is so dirty as to be worthless. Stainier[56] states that, in the Andanne or eastern district of the Liége basin, the Chokier consists chiefly of dark laminated shale, utilized in manufacture of alum. The Andenne, mostly shale, has the lowest coal seam at 80 to 130 feet meters above the Lower Carboniferous limestone. It is thin, without value, and underlies a sandstone, often 20 meters thick. On this rests a mass of shales containing the only workable seam, known as Plateur-de-Rouvroy, Pélémont, Six-Mai and Grande Veine, which at times is one meter thick, though usually between 50 and 60 centimeters. It is terroulle, an intimate mixture of coal and clay, burning slowly and without flame. Almost invariably it is in two benches, one giving fine, the other lump coal. At the western extremity of the district, this seam divides, but the benches retain their character. The roof is marine in the eastern portion, containing *Lingula* and *Loxonema.* The poudingue houiller has beds of conglomerate with pebbles, at times, of one decimeter diameter; it would seem that these conglomerate layers are merely lenses.

Smeysters[57] notes that, in the eastern part of the Hainaut basin, the lower Westphalian has an extreme thickness of 350 meters, but

[54] M. Mourlon, "Géologie de la Belgique," 1880, t. 1. p. 119.

[55] Geologie der Steinkohlenlager," p. 280.

[56] X. Stainier, "Bassin houiller d'Andenne," *Bull. Soc. Belg. de Geol.,* t. VIII., 1894, Mem., p. 3–22.

[57] J. Smeysters, *Ann. Mines de Belg.,* t. V., 1900, pp. 1–128.

it decreases toward the east, becoming only 150 beyond Namur. Three coal seams are in the middle stage (Andenne), all of which are mined locally in the eastern part of the basin. *Calamites* and *Stigmaria* are abundant. A thin coal seam near the top has a marine roof. Conglomerate is of only sporadic occurrence in the Poudingue houiller.

Stainier,[58] in the Charleroi and Basse Sambre districts, found the equivalent of the Andenne Plateur-de-Rouvroy in the Veine du Calvaire, which is 50 to 60 centimeters thick; it has been mined for many years. This bed is at 110 meters below the Poudingue. The lowest seam, Fort d'Orange, is half a meter thick and yields an excellent coal of the terroulle type, its composition being: volatile, 10.5; fixed carbon, 84.34; ash, 5.16. The coal seams are all very thin in Charleroi and a similar condition exists in Couchant de Mons. Cornet[59] has shown that the Chokier fauna in the latter district is wholly marine, but of littoral type. The deposits are fine-grained, but he shows that this is no proof of deep water, for the great proportion of the forms are mollusks with byssus. Seventy per cent. of the Coal Measures deposits are fine material. He is convinced that lowland surrounded the area of deposition.

The Westphalian (Upper Westphalian) has, in ascending order, the assises of Chatelet, Charleroi and Flénu.

The Chatelet is poor in coal and the seams are thin, though less irregular than those of the Andenne. In the Liége district, two seams are worked, Chesson and Grande Pucelle or Désirée, 70 and 60 centimeters thick.[60] The former has a marine roof, which Dannenberg believes equivalent to that of Ste.-Barbe-de-Floriffoux in Charleroi district and very probably to that of Breitgang in Eschweiler, Finefrau-Nebenbank in Ruhr. The coal of Grande Pucelle has 16 per cent. of volatile at the south, but only 6 per cent. in the northern, the less disturbed portion of the district. Very little of the Chatelet remains in the Andenne district and but one seam is mined. This, the Chenevis, at 120 to 160 feet above the poudingue

[58] X. Stainier, "Stratigraphic, etc., de Charleroi et de la Basse-Sambre," *Bull. Soc. Belg. de Geol.*, t. XV., 1901, Mem., pp. 1–60.

[59] J. Cornet, "Le terrain houiller sans houille (H1 *a*)," *Ann. Soc. Geol. de Belg.*, t. 33, 1906, Mem., pp. 139–152.

[60] A. Dannenberg, op. cit., p. 280.

houiller, has a typical mur and the toit is rich in plant remains. Stainier[61] thinks that the poverty of the Chatelet in the Hainaut basin is remarkable, there being only one generally workable seam, though some veinettes are mined locally. The V. Leopold. known under many names, is 100 to 140 meters above the poudingue and attains workable thickness at numerous places. At 50 meters higher is the V. Ste.-Barbe-de-Floriffoux, which is thickest midway in the basin, where it is in two benches, 10 and 40 centimeters, separated by a shale parting of 80 centimeters, and yields a coal having volatile, 17; fixed carbon, 68.72; ash, 14.28. The mur is white, silicious, with *Stigmaria,* and is from 0.30 to 1 meter thick. It bears great resemblance to the English ganister. The roof is black laminated shale with marine fossils. Stainier has described at least six horizons of fossils, one of them unmistakably marine, the others probably brackish water. The Chatelet coal seams become wholly unimportant toward the west.

The Assise de Charleroi is divided in the Liége district into St.-Gilles, Liége and Seraing faisceaux, 200, 350 and 400 meters as extreme thicknesses. The coal seams are 9, 14 and 13. All are thin, rarely reaching one meter, but the Grande Maret, at base of the Liége faisceau, averages 1.80 and sometimes reaches 2.12 meters; it has three partings, 77 centimeters, and is the only seam in this faisceau which is mined systematically; the Grand Bac, next above it, is mined at some localities. Only two seams of the Seraing, the Stenaye at base and the Houilleux next above, are worked; but these are exceedingly variable. The marked marine horizon in roof of Grand Bac is thought by Dannenberg[62] to be equivalent to that over Coal 6 of Mine Marie in the Aachen and that of Catharina in the Ruhr basin. He correlates Charleroi with Saarbrückian.

Charleroi deposits have been removed from the Andenne district but they are important in the Hainaut basin. Stainier finds three faisceaux, Sablonniére, des Ardennoises and Goufre. The upper part of the Sablonniére is no longer accessible, but there are six workable seams and several streaks in the lower portion. Almost all of them have a faux-toit, sometimes cannel-like, and are divided

[61] X. Stainier, *Bull. Soc. Belg. Geol.,* t. VIII., 1894, pp. 17, 20.

[62] A. Dannenberg, op. cit., p. 284.

into benches. The lowest seam, like Ste.-Barbe-de-Floriffoux, has the *en chapelet* structure and shows extraordinary changes in thickness. The middle faisceau has 16 seams, 0.45 to 1 meter thick, many of which have a faux-toit of gallet, or of shale and coal, and a typical mur. The roof in some cases contains *Naiadites* and *Carbonicola.* One seam has *en chapelet* structure; intervals between seams vary, apparently without rule. The Goufre or lowest faisceau is the most important, having 10 workable seams, 4 of them more than 1 meter thick, and all more regular than those of des Ardennoises. The highest seam, V. Anthracite, is often absent, having been removed during deposition of the overlying sandstone, which occasionally reaches almost to the V. Caillette, 3 meters below. V. Anthracite is seldom thicker than 30 centimeters and its coal has but 8.80 per cent. of volatile, much less than that in any seam below it. The V. Tatonie has sandstone pebbles and is very close to the underlying Grés de Hamm, which is 10 to 12 meters thick and closely resembles the poudingue houiller; like that, it contains grains and pebbles of bright coal. The thickest seam, Dix-Paumes, has 1.28 meter of coal on the north and south sides of the basin, but is much thinner midway. It contains pebbles of quartzite and fragments of gallet, a cannel-like shale. The coal is excellent, with 16.1 per cent. of volatile and only 3.5 of ash. V. Gros-Pierre, Stenaye of the Liége district, is irregular, usually present at the east but disappearing toward the west. It has, at most, 0.93 of coal in 4 benches; its coal has a fibrous structure and frequently contains pebbles of quartzite. Its thin faux mur rests on sandstone, which has *Stigmaria* in the upper part. A cross-bedded sandstone is persistent in the faisceau Goufre. The conditions farther west in Hainaut are not materially different from those already described.

The Flénu deposits are confined practically to the district of Couchant de Mons, in much of which the coal is buried deeply, but mining operations are extensive. The coal is much richer in volatile than that of the Charleroi but peculiarities of seams and of the interval rocks are much the same. The lowest seam[63] is the Petit-Buisson, which has a well-marked marine roof, whence Cornet ob-

[63] J. Cornet, "Seconde note sur les lits a fossiles marins," etc., *Ann. Soc. Geol. Belg.*, t. XXXIV., 1907, Bull.., p. 93.

tained *Orthoceras, Lingula, Pernopecten* and *Carbonicola.* Renier[64] states that this coal seam was covered by ocean water soon after deposition, so that at some localities it has been replaced with dolomite. This dolomite encloses the vegetable pulp of the swamp, little changed.

The mass of deposits decreases toward the east. Andenne from 340 to 170 meters; Chatelet, from 400 to 288; Charleroi is 1,270 in Couchant de Mons but only 970 in the Liége district. Four coal seams at most are in the Andenne; the same number in the Chatelet, but they are unimportant except in the Liége district; Charleroi is rich throughout, having 19 workable seams in Couchant de Mons with 10.70 m. of coal, 20 in Charleroi, with 16.85 m., 23 in Liége with 17.45 m. of coal. Flénu in Couchant de Mons has 45 seams with 27.20 m.; besides these, each more than 30 centimeters thick, there are many veinettes, which rarely become thick enough for local operation.

Intervals between coal seams vary almost capriciously. Smeysters[65] notes many instances in the eastern part of Hainaut basin; one may mention here only that between the Mere-de-Veines and the Crevecœur. This interval is usually 10 or 12 meters, but at one locality, it is reduced to 60 cm., yet within a short distance the normal interval was observed. The coal seams are equally variable and some of them, as mentioned by Stainier, resemble a string of huge beads. Several seams are persistent enough to be utilized as horizons, but great variability characterizes all.

Many years ago, Cornet[66] grouped the Belgian coals into (1) houille maigre à longue flamme ou houille flénu; (2) houille maigre à longue flamme ou demi-grasse; (3) houille grasse maréchale ou houille grasse; (4) houille sèche à courte flamme ou houille maigre. (1) is brilliant, with conchoidal fracture, ignites readily, yields much illuminating gas, but the coke is not well fused; (2) has shaly fracture, often has fusain, yields excellent but not strong coke; (3) gives a coke good for all purposes; while (4) burns slowly and the coke is

[64] A. Renier, "Les relations géologiques du Bassin houiller du Nord de la France avec les gisements belges," *Bull. Asoc. Ing.,* Fasc. 1, 1919, p. 18.

[65] J. Smeysters, *Ann. des Mines,* t. V., 1900, pp. 103–106.

[66] F-L. Cornet, "La Belgique Minerale," *Catalogue of Paris Exposition,* 1878, Separate, pp. 18–25.

not fused. He remarks that the volatile decreases downward in the measures but he notes also a variation along the direction of strike and still more notable decrease from the disturbed southern area northward into the slightly disturbed area along the northern border.

Renier[67] offered a somewhat different grouping; Flénus, with more than 25 per cent. of volatile; Gras, with 25 to 16; Demi-gras, with 10 to 11 and Maigre, with less than 11. Gallet, resembling bituminous shale, is closely allied to cannel. The different benches of a seam are often unlike in volatile content and there are local variations which are puzzling. At the same time it seems possible to find a law of variation in order of superposition; equally so in a single seam along general direction of the trough, or even in a direction normal to the line of the trough. The downward decrease is thus, Flénu, maximum, 35 per cent.; Charleroi, 24; Chatelet, 18; Andenne, 15. But in the Flénu, the volatile varies from 25 to 35; in the Charleroi, from 17 to 20 within Couchant de Mons, 17 to 18 in Centre, 10 to 18 in Charleroi, 13 in Basse-Sambre, 0.5 to 21 in Liége district; the Chatelet from 6 to 10 and the Andenne from 7 to 15.5. He thinks that Hilt's law is practically applicable to the Belgian area. But the volatile increases from north to south, that is, from the less disturbed to the intensely distorted area. Finally, the volatile decreases from the outcrop toward the deeper part of the basin.

Dannenberg,[68] utilizing tables of analyses compiled by Stainier, makes clear that, in the Liége district, the volatile of the respective faisceaux of the Charleroi decreases downward from 23.7 in the upper St. Gilles to 6 per cent. in a seam near base of the Seraing. But there are exceptional seams; one in the upper Liége faisceau has abnormally low volatile, being anthracite, while one in the upper portion of Seraing has 24 to 25 per cent. and is the richest gas coal in the district. More important are the variations across the basin from north to south. In the northern portion, the "Plateurs," where disturbance is comparatively slight, the percentage is low, but it increases greatly in the southern portion, where the disturbance

[67] A. Renier, op. cit., 1914, pp. 23–30.

[68] A. Dannenberg, op. cit., p. 285.

was extreme. In four important seams of the faisceau Seraing, the percentages at the north are 13, 7.3, 6.2, and 6, but these increase southwardly to 20.8, 18, 15.5, 16.6.

France.—Passing into the Department du Nord in France, one reaches the Valenciennes basin, which is continuous with the Hainaut basin at the east and with that of Pas-de-Calais at the west. According to Barrois, the Coal Measures come to the surface in a comparatively small area near the Belgian border but elsewhere they are largely covered by later formations, so that mining operations were begun at much later date than in Belgium. During Trias, Jura and Lower Cretaceous time, the Coal Measures were exposed, and erosion removed them from a great area. The limits of the coal deposits have been determined approximately by borings, but the region has been disturbed so seriously by folds and overthrust faults, especially along the southern border, that the succession can not be determined beyond doubt. The basin is from five and a half to sixteen kilometers wide. The coal seams are numerous, fairly uniform, but are thin, rarely exceeding one meter and averaging about 70 centimeters; under favorable conditions, some only 35 centimeters thick, have been mined. The actual number of workable seams can hardly be determined; Olry attempted to ascertain it. Going from north to south, he found in the several faisceaux, beginning at the bottom,

A, in the northern portion,

faisceaux 1, 2, 3, 35 seams; 4, 31 seams; 5, 36 seams;

B, in southern portion,

6, 25 seams; 7, 16 seams; 8, du Marly, 3 seams, in all 146 seams. But paleontological work by Barrois and Paul Bertrand[69] has proved that this number is much too great. The seams appears to be superimposed as Olry supposed them to be, and the change in chemical composition is singularly regular in the order; but certain seams have been recognized in both portions of the region, though differing in facies and in composition. Barrois states that the seams of faisceaux 1 and 8 must be ignored, that faisceaux 5 is superimposed only

[69] C. Barrois, "Exposé de l'etat de connaissance sur la structure géologique du bassin houiller dans le Department du Nord," Lille, 1909, pp. 1–22.

in part upon 4 and so has only 15 seams. The number of workable seams does not exceed 77 and even that estimate may be excessive. The zone of Flines, equivalent to Andenne of Belgium, gives evidence of at elast five invasions by the sea.

The Concession of Dourges was studied many years ago by Breton.[70] He recognized a general decrease in volatile downward in the section, but the change is not in accordance with an exact law, for it is true only of seams far apart, not of those near together. Similar variation is observed in a seam, when followed for a considerable distance. The roof in each case has its own plants along with others not peculiar to it. The exposed section in southern Dourges is about 750 meters thick with 80 coal seams, measuring from one centimeter to a meter and a half. The area is greatly disturbed by folds and faults.

There are 36 beds of sandstone, the thickest being 22 meters. They vary greatly but not abruptly and consist of quartz grains with clay and some mica. Occasionally, they contain pockets of bright coal, and trunks of trees are not rare. Sandstone, at times, replaces a coal bed, though the mur and toït persist in such cases. Shale in roof of a coal seam is darkest near the coal but the best impressions of plants are at about a half meter above. He notes one marine deposit, about 7 meters thick, containing many specimens of *Productus* and *Orthoceras*.

Breton groups the coals into grasses, which ignite readily, are rich in gas, fuse well, give off dense smoke and leave a white ash, and sèches, less easily ignited, burn slowly, give less smoke, do not agglutinate and leave a reddish ash. These often have much mineral charcoal, which bears close resemblance to wood charcoal. Coal seams usually have shale at top or bottom or as partings, which, in the fat coals, is combustible and is used as fuel for the boilers or is given to the poor. He emphasizes the fact that, very often, there is a veinette near a thick seam, with which it is apt to unite.

He groups the deposits into faisceaux. The highest is that of the charbons tres-gras, shown in the eastern part of the Concession. This, about 300 meters thick, has 7 workable seams with 6.15 meters

[70] L. Breton, "Étude géologique du sud de la concession de Dourges," *Soc. des Sci. Lille,* 1872, pp. 355–422.

of coal; 10 which may be utilized when the thicker ones have been exhausted, and 8 which are too thin ever to be mined. The highest seam is the Ste.-Barbe, with maximum of a meter and a half, which is double—a characteristic of the thicker seams. Veine 9, long mined at one colliery, is of uncertain value, for within a few meters it may change in thickness from 3 or 4 meters to a petty veinette. It is always in a single bench and has a faux-toit. The coal is very clean and much prized for manufacture of illuminating gas, though it has little lump. The thickest seam is the Veine a trois sillons, with 0.60, 0.40, 0.40 of coal and 0.30 of bituminous shale in two partings; it yields 60 per cent. of lump coal.

The faisceau de charbons gras, 190 meters thick, has 5 workable seams with 3.50 meters of coal. The seams are irregular and some of them are merely local; one, a meter thick at the west and yielding excellent lump coal, becomes poor toward the east and at length is replaced with sandstone. In its roof are vertical *Calamites,* of which the roots are in the coal. The demi-gras faisceau has five thin but workable seams, one of which has *Stigmaria* in the roof.

Coals from the highest faisceau have 28 to 32 per cent. of volatile, those of the middle have 25 to 28, and those of the lowest have 22 to 25. Breton asserts seams cannot be identified or their position determined by means of composition.

Rock Fragments in Coal.—The presence of rock fragments in coal seams has been observed by Stainier and Schmitz in Belgium and by Barrios in France.

Stainier[71] found rolled pebbles in the 500-meter level of a seam near Charleroi, where they are not uncommon; but none has been found in the 250-meter level. They are rounded and have a coaly covering. The dimensions of two of them are 0.07 by 0.045 by 0.10 and 0.14 by 0.08 by 0.16 meter. These are quartzitic sandstone. A similar pebble from a seam in the Huy district is 0.15 by 0.10 by 0.04, rudely triangular and the edges are rounded. Schmitz obtained from the Veine Leopold near Charleroi sandstone pebbles, perfectly rounded and covered with a crust of coal. Stainier saw large, rounded pebbles in the Grande Veine at Gosselius. They are pres-

[71] X. Stainier, "On the Pebbles found in Belgian Coal Seams," *Trans. Manch. Geol. Soc.,* Vol. XXXIV., 1896, Sep., pp. 1–19.

ent in the Grande Veine of Centre, that of Charleroi, Dix-Paumes, Gros Pierre, Caillette and other seams. Some have been discovered in partings, in the roof and in the mur. The largest weighs 25 kilogrammes and most of them are sandstone. Stainier thinks that these pebbles must have been entangled in roots of trees, floated into the sea.

Schmitz[72] asserts that rolled pebbles are not so rare as some writers have supposed; they are not exceptional but are of common occurrence throughout the coal formation. He thinks that they confirm sympathy for the French doctrine, which assumes that the plant materials were changed into coal before burial in deltas. He suggests that, on the shores of coal lagoons, movements of water more or less rapid had brought fragments of rock with the vegetable alluvium; a long voyage in the *bouillie vegetale* would bring about the coating of coal.

Barrois's[73] exhaustive study was based upon a collection of more than 300 pebbles made in the Veine-du-Nord at mines of the Compagnie d'Aniche. The seam is regular and, though thin, 0.45 to 0.60 meter, it has been mined profitably for a long time. The coal is of excellent quality, demi-gras, with 13 per cent. of volatile and comparatively little ash. The mur has abundance of rootlets and at half a meter below the coal there are many large rhizomes of *Stigmaria* with appendages. The roof is fine shale, without animal fossils, has no erect stems but has impressions of *Lepidodendron* and Calamites. The faux-toit is shale and coal, never more than a half meter thick.

The pebbles vary greatly in shape and are distributed irregularly in the coal from mur to toit. Their position indicates that they were not brought in by currents and some have salient angles, which would have been destroyed by even gentle rubbing. The crust is coal, laminated and brilliant, often with pyrite, derived from the coal. It is adherent, is removed only with difficulty and contains more volatile than is found in the surrounding coal.

[72] G. Schmitz, "A propos des cailloux roulés du houiller," *Ann. Soc. Geol. Belg.*, t. XXI., 1894, Bull., pp. lxxi–lxxv.

[73] C. Barrois, "Galets trouvés dans le charbon d'Aniche (Nord)," *Ann. Soc. Geol. du Nord,* t. 36, 1907, pp. 248–330.

The pebbles differ in character. Some are of feldspathic sandstone, the feldspar being completely decomposed. These, at times, contain fragments of Coal Measures plants. Others are quartzites of types belonging to the Coal Measures; but there are some which appear to be of Cambro-Silurian origin, though without fossils and some are of gneiss. Eighty-six per cent. are from the Coal Measures, 2 from Cambro-Silurian and 12 are from the Archean. The Carboniferous specimens are from the Flines (Andenne) and Chokier assises (Namurien of Stainier). The forms vary; subangular, 63 per cent., and rolled, 37. The weights are 1 gramme to 1 kilogramme, 73 per cent.; 1 to 10 kilogrammes, 24 per cent.; and still heavier, 3 per cent. The largest are of sandstone.

There must have been land where coal rocks and those of earlier age were exposed. The area of outcropping coal rocks must have been extensive and near at hand, as is evident from shape of the specimens. These were from the north side of the trough, where the rocks had become hard before tectonic disturbance occurred. All efforts to explain their presence as due to torrential action must be abandoned. The pebbles had been exposed for a long time; some were wasted by rubbing, others seem to have been worn by moving strata or by wind action; but all evidence shows that they endured long alteration in free air.

Erect Stems—Stainier[74] has described erect trunks observed by him at two localities. At the Falisole colliery, the Veine Lambiotte rests on a sandstone, containing a veinette, which occasionally unites with the main seam. At usually 4 but occasionally 12 meters above the coal is a veinette, which at one locality unites with it. In this interval numerous trunks were seen, but they are without roots and all features indicate that they are merely "snags." At the other locality, the trunks are cut off by faulting, but the evidence presented by Stainier does not suggest that the stems are *in loco natali.* The seam at this place shows signs of erosion during deposition of the overlying sandstone. Smeysters[75] has described the mode of occur-

[74] X. Stainier, "Un gisement de troncs d' arbres débout au Charbonnage de Falisole," *Bull. Soc. Belg. de Geol.,* t. XVII., 1902, Mem., pp. 69–76. The same, 1903, pp. 539–544.

[75] J. Smeysters, "Note sur les troncs d'arbres fossiles," *Ann. Mines de Belgique,* t. X., 1905, pp. 1–12.

rence of several vertical stems in a mine near Charleroi; but these seem to be transported fragments; there is no reason for supposing that they are *sur place*.

Schmitz[76] in 1895 found 33 stumps of erect trees in the roof of the Grande Veine at Grand Bac in the Liége district, where the coal seam is vertical. The glossy, brilliant basal surface of the roof is exposed in the wall throughout and observers could determine the circular markings, indicating bases of the trunks. In almost every case, the cylinders of these petrified trees retained the bark, coalified, sometimes a centimeter thick, under which were leaf scars showing that they are *Sigillaria*. As the stems are vertical to the stratification, detailed study of their surface was impossible. The exposure is on the north wall of the gallery, 2 by 93 meters, giving to each stem a space of 5.60 square meters, a condition favoring belief that they are *in loco natali*. But the stems are distinctly cut off sharply at approach to the coal. Most of them show the swelling which belongs near the roots, but no trace of roots appears. It is clear that the rooting of these trees could not be in the toit, for that is merely a few centimeters of carbonaceous shale. This thin toit contains many impressions of plants and stalks of lycopods and equisetaceæ, all lying flat. Four of these were seen passing across the base of a trunk, which proves that the stems are not *in loco natali*.

But the whole condition indicates rather that the overlying rock, penetrated by the trunks, has slipped on the coal during the disturbance. This polished the surface at the plane of contact and cut off the stems as sharply as though they had been sawed. Schmitz, in a later article, recognized this condition and regarded the forest as *in loco natali*. Long ago, Breton,[77] in his description of the Concession of Dourges, stated that, in some mines, *Calamites* were found normal to the bed, in the place where they grew. The roots often rest on the coal and the stems traverse the roof. In the pit, Ste.-Hermite, one can see in a gallery, 60 meters long, a number of *Calamites*, resting by their thin part on the coal, the stems penetrating the over-

[76] G. Schmitz, "Un banc à troncs débout," etc., *Bull. Acad. Roy. de Belg.*, III., t. XXXI., 1896, pp. 260–266. "Formation sur place de houille," *Rev. des Quest, Scient.*, April, 1906, p. 31.

[77] L. Breton, op, cit., pp. 383, 389.

lying shale, 3 meters thick. Sandstone overlies the shale and it fills the *Calamites* to their roots, which are in the coal. *Sigillariæ* are sometimes vertical to the stratification. *Stigmaria* characterizes the mur and sometimes is found in the roof.

Boulay[78] states that in the roof of mine Veine Christiane within the Concession of Bully-Grenay, in Pas-de-Calais, he saw great erect trunks of *Sigillaria,* 30 to 60 centimeters in diameter. The species was not determinable, but the roots are unquestionably *Stigmaria abbreviata.* This seam is higher in the section than the Ste.-Barbe of Dourges. Bertrand[79] examined two erect stems in a mine within the Lens Concession of Pas-de-Calais. One, in roof of the Veine Désiré and not absolutely vertical, has its base resting on a coaly film; underneath the veinule is abundance of *Stigmaria* rootlets and a great *Stigmaria* rhizome was seen; but this could not be traced as a slip had occurred at the horizon of the veinule, so that no proof could be obtained that this *Lepidodendron* stump is in its original place. The other stump, a *Sigillaria,* was in roof of a seam, 14 meters above Désiré; the broadened base rests directly on the seam and its roots cannot be traced; if it be *in situ,* the roots would be unrecognizable, as they wiuld have been changed into coal. The stump directly above Désiré is cut off at base as though sawed. This is a common condition, observed in other coal areas.

Barrois[80] discussed the matter generally in connection with description of vertical stems at many horizons in the Lens and Liévin Concessions within Pas-de-Calais. The existence of such trees had been known for a long time and they had been regarded usually as being in the place of growth; but latterly some geologists have maintained that they had been transported, A recent discovery of erect trees in the roof of the Veine Leonard of Liévin seems to confirm the later explanation. He presents a diagram, drawn carefully to a scale, which shows the relations. The trees are parallel, are envel-

[77] L'Abbe Boulay, "Recherches de palaeontologie végétale," etc., *Soc. Scient. Bruxelles,* 4me année, 1880, p. 32.

[79] P. Bertrand, "Note sur des arbres, débout à la fosse No. 3 des mines de Noeux," *Ann. Soc. Geol. Nord,* t. 37, 1908, pp. 50,51.

[80] C. Barrios, "Note sur la repartition des arbres débout dans le terrain houiller de Lens et de Liévin," *Ann. Soc. Geol. du Nord,* t. 40, 1911, pp. 187–196.

oped in shale, with roots at the lower end, which do not penetrate the coal; at least, if they do, they have been converted into coal and become unrecognizable.

During a number of years, Barrois, P. Bertrand and some other geologists had studied the roofs of coal beds and they succeeded in classifying them into (1) roofs of sandstone, the grains varying in coarseness, containing much vegetable débris, but leaves have disappeared; (2) roofs of shale, carbonaceous, with plants, the leaves in fine condition, showing that they had not been transported far and that the deposition had been made in quiet, shallow water; (3) roofs of bituminous shale, black, ampelitic, and with fish remains; always very thin; the deposit was made slowly and the water was not free from mud; (4) roofs of bituminous shale, brown, contains lamellibranchs of deep- and brackish-water types; these also were formed slowly and the water was not deep or agitated violently; (5) roofs of calcareous shale with marine shells; the water was deeper and liable to greater movements.

If the trees had been floated in, they should occur in roofs of deep water origin, they should not be in roofs, formed in water so shallow that they could not be introduced in vertical position. But they are present in shallow water roofs. At Liévin, they have been obtained from 19 veines or passees (veinules) with typical shallow water roofs and from 7 roofs of intermediate types. Distinctly deep water roofs are not wanting, there being 28 of them, not one of which contains erect trees. Barrois regards the evidence as sustaining the assertion of *in situ* origin for the stems.

The Central Plateau of France.—The coal basins of central France, about 300 in number, are in large part of little more than local importance; but some of them are extremely important because the seams attain great thickness and yield a high-grade fuel. All are of limnic origin and the Coal Measures deposits belong mostly to the Stephanien. The general features are much the same in all, so that it is necessary to refer only to the basins with which all are familiar.

The Coal basin of the *Loire* or of *St. Étienne* was studied by Gruner, whose report was published in 1882 and by Grand'Eury,[81]

[81] L. Gruner, Bassin houiller de la Loire," Paris, 1882, pp. 168–173, 204–237, 483–486; C. Grand 'Eury, "Bassin de la Loire," *C. R. Cong. Int. Geol.*, Paris, 1900, pp. 521–543, *Livret-Guide des Excursions*," XIb., 1900.

whose results, chiefly from the paleobotanist's standpoint, were presented in many memoirs. Two papers, published by the International Geological Congress, may be accepted as summarizing his conclusions.

According to Gruner, the succession, ascending is:

Brêche de la base; Étage houiller de Rive-de-Gier; Étage sterile de St. Chamond; Étage houiller inférieur de St.-Étienne; Étage moyen de St.-Étienne; Étage supérieur de St.-Étienne; Étage sterile, or Permo-Carboniferous of Grand'Eury.

These outcrop in concentric curves, now broken and distorted by faults. The basin embraces about 80 square miles; the second and third stages occupy not far from nine tenths of the area, if they exist under the higher divisions; the fourth is present in almost one half of the basin; the fifth, in less than one fourth, while the sixth and seventh are in less than one twelfth.

The Brêche is a confused mass of angular fragments, slides from primitive rocks, surrounding the basin, and nature of the fragments differs according to locality, granite prevailing at some, gneiss at others. It is from 20 to 200 meters thick and the top is at 15 to 20 meters below the lowest coal seam.

The Rive-de-Gier, consisting of sandstone with some shale, is 100 to 120 meters thick and has four workable coal seams, as well as several thin streaks. The highest, Grand Masse, is divided by a parting of white sand, known as Nerf blanc and not more than 10 inches thick. Coal from the lower bench is hard, dull, contains much oxygen, is good fuel for grates and is termed "rafford"; that from the upper bench, termed "maréchal," is tender, brilliant, has less oxygen than the other and is excellent for gas and coke. In the western part of the area, coal from both benches has less volatile than at the east and, in the last concessions, it becomes anthracitic at depth of 500 to 600 meters. At the eastern limit of the Rive-de-Gier, the Grand Masse is from 0 to 0.50 meter thick; but it increases toward the west and becomes 15 meters at Grand'Croix. It thins away at the borders of the area. The roof is sandstone; during its deposition, the coal suffered much from erosion, all having been removed at numerous places; the mur is tender, often swells and replaces much of the coal. The seam, les Batardes, 35 meters lower,

is double with a parting, 0 to 8 meters thick. The coal thickens and improves in quality toward the west, becoming 5 meters near Grand-'Croix, where the benches are united. The roof of the upper bench is sandstone and erosion of the coal is frequent; but that of the lower bench is shale and the coal is always regular. Two lower seams have poor coal; one has maximum thickness of 1.40 meter near Grand'Croix, but the other is a lens, disappearing in all directions.

Beyond the Rive-de-Gier, one reaches the sterile stage of St.-Chamond, 500 to 800 meters thick, the lower portion a coarse conglomerate, the upper less coarse and micaceous. The upper or micaceous division is thin at southeastern localities but it increases at expense of the lower portion until, near St.-Chamond, it has replaced it almost wholly. Thin coal seams occur in the area of coarse deposits but they disappear when the micaceous beds predominate.

The Étage de St.-Étienne inférieur, 850 to 950 meters thick, has 10 to 12 coal seams, some of which occasionally divide. They vary abruptly in thickness as well as in quality of the coal. Seams 8 and 12 at times yield excellent coking coal but at others they are so dirty as to be worthless. Coal seams are regular where the rocks are quartzo-feldspathic but become worthless or disappear when the rocks are micaceous. The upper division has one important seam, 0 to 6 meters thick, which suffered much from contemporaneous erosion, having been removed wholly in many places. The coal is good for coke, though it must be washed to remove the high ash. The coal of this stage was formed of *Cordaites, Psaroniocaulon, Aulacopteris* and *Calamites*.

The Middle stage of St.-Étienne, about 350 meters thick, has 8 or 9 coal seams separable into two divisions; the lower has two seams. In the upper, Nos. 1 and 2 have inferior coal containing kidneys of iron ore and trunks of trees, replaced with carbonate of iron. Ordinarily they are not mined, but No. 2 occasionally becomes 3 meters thick and has good coal. Nos. 2 and 3 are united at many places; the latter averages 4 to 5 meters; No. 4 is ordinarily at 20 meters below 3, but the interval varies from 0 to 24 meters. At times, No. 3 is 10 and 12 meters thick, but in such cases it consists of 1, 2, 3 and 4 united. The coal of this stage originated from the same plants as in the Lower St.-Étienne.

The Étage supérieur de St.-Étienne, 250 to 350 meters thick, is in an area of 1,000 to 1,500 meters wide by 11 kilometers long. It has 10 or 12 coal seams with total extreme thickness of 15 to 20 meters at the east but diminishing rapidly toward the west, where micaceous shales prevail. The lowest seams are of moderate thickness and yield inferior coal. The seams in the middle are 2.50 to 7 meters and are good. The highest seam, 3 to 10 meters, yields friable coal. In all cases the coal is rich in volatile and appears to be composed of *Psaroniocaulon, Stipitopteris* and *Calamites.*

The upper sterile stage or Permo-Carboniferous, apparently not more than 475 meters thick, consists of shaly green and red sandstone. The passage from St.-Étienne is gradual and, as far as can be gathered from Gruner's statements, the succession is conformable.

Gruner notes that the forests of this basin are confined to the Middle St.-Étienne. Long ago, the upper one was described by Alex. Brongniart.[82] Though are rocks are horizontal, they have suffered from a slight movement, which has broken the continuity of many stems, so that the root portion has been shifted. Eighteen vertical stems are shown on the plate, which represents about 75 feet of the wall, and roots are distinct on many of them. Brongniart was confident that this is part of a forest of bamboo-like plants. The interior of the stems is filled with sandstone like that in which they occur; but this is coated by coaly or ferruginous material.

Gruner says that another forest is at 100 meters lower in the section. He saw in the Treuil mine 12 trunks in a space 12 meters square. These rest directly on the coal, which is not penetrated by the roots, though in some cases they spread out upon it. These are *Sigillaria.* Similar conditions were observed elsewhere. The relations in the mur are different from those observed in the roof, for at St.-Étienne he saw rootlets descending from the coal into the underclay. This condition is especially clear in les Batardes of the Rive-de-Gier, where *Stigmaria* abound in the mur. His discussions on pp. 168–173 and 483–496 should be consulted by all who are interested in the matter.

[82] Alex. Brongniart, "The Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines,* 1821; translated in de la Beche's "Selection of Geological Memoirs," etc., London, 1836, pp. 208–216.

Grand'Eury presented to the Geological Congress a paper in which he discussed elaborately the occurrence of various types of plants. He regards the deposits as Stephanien. The paper in the Guide gives more of detail respecting localization.

The Upper Sterile stage passes upward into coarse conglomerate, which Stur thought analogous to the Rothliegende of Rossitz; but there is no unconformity. The Rothliegende flora is not abundant. *Cordaites* and *Pecopteris* are present and *Tæniopteris abnormis* has been found but no trace of *Callipteris* has been observed. *Walchia* pinniformis was seen in the St.-Chamond, but it does not continue into the St.-Étienne stages. The Avaize (Middle St.-Étienne) contains precursors of the Permian.

The Productive Coal Measures show erect trees with their roots, associated with well-preserved plant impressions, all indicating autochthonous vegetation. Rooted trunks and stumps are uncovered daily near St.-Étienne. His belief is that the trees, in every case, grew in water with their roots penetrating the ground below. In many cases, the stems have been removed during mining work but usually the vegetable soil was not disturbed; it is traversed by roots, some herbaceous, some ligneous, which often pierce impressions of leaves. *Stigmaria* is the most common form. These have their roots spread out in normal position and frequently retain the delicate appendages. They penetrate the underclay and are interlaced in it. There are many other types, which he regards as even more satisfactory. Chief among these is *Calamites,* whose erect stems give off rhizomes, which, in turn, give off rootlets; all of the subterranean organs are well preserved and are in normal position. *Calamodendrons* have their stems bound to the soil by a complete system of roots. *Psaronius* stems are very numerous and are surrounded at base by innumerable roots, pushed down obliquely into the soil. When the plant, subjected to accumulation of alluvium, was obliged, in order to live, to give off free roots in the water, these passed downward and buried themselves in the soil below. Stumps of *Cordaites* are equally numerous with their woody roots, divided and subdivided even to rootlets, which have a comb-like arrangement. *Syringodendrons,* with complete *Stigmaria* roots and rootlets are of frequent occurrence. Fossil fruits are abundant. Roots of

stumps are involved in a maze and he has observed cases where the roots of one stump penetrate stumps at a lower horizon. Some long roots cross several layers of subjacent rock. He is convinced that the fossil forests were developed *sur place.*

Commentry.—The petty basin of Commentry, though embracing barely six square miles, is perhaps more familiar to geologists than is any other of the Plateau basins, St.-Étienne alone excepted. It was studied during many years by Fayol,[83] who described it in an elaborate memoir and utilized the results as basis for his well-known Delta hypothesis. This memoir is so detailed and contains so much of interest that it is difficult to prepare a synopsis of the facts bearing on matters concerned in this study.

The basin is a depression in Archean and apparently contains no rocks older than the higher Carboniferous. It is divided into five strips, extending from north to south: Bourdesoulles, at west, containing coarse rocks; Le Marais-les Ferriéres, sandstones, shales and coal seams; Montassiègè sandstones and blocks of rock; Les Pegauds, sandstone, conglomerates, shale and coal seams; Longeroux, at east side, conglomerates. Montassiègè separates the sub-basins of Les Ferriéres and les Pegauds, which together make up barely one third of the whole area and in each case have only a very small space occupied by coal. The coarser rocks predominate throughout, shale and coal being only 4.5 per cent. of the whole mass.

The important coal deposit of les Pegauds has an outcrop rudely resembling the capital letter C. At the easterly extremity, it begins as a single seam of insignificant thickness, but increases along the curved outcrop, dividing and at last thinning away to disappearance on the east side of Montassiègè, where it is represented by 8 thin seams within a vertical section of 200 meters. Southwardly within the curve, it dips at 0 to 50 degrees and finally comes to an end at a depth of 350 meters. Near Longeroux, at the east, the thickness is only a few centimeters, but at the northerly part of the outcrop, the main portion, known as the Grande Couche, averages between 10 and 12 meters for a distance of 2.5 kilometers. Thence westwardly it decreases to disappearance. The coal for the most part is caking and

[83] H. Fayol, "Études sur le terrain houiller de Commentry," Liv. prem. St.-Étienne, 1887.

with long flame, but it varies greatly. One finds it passing from coal to cannel, boghead, bituminous shale and even to sandstone or conglomerate. Sometimes it is clean from floor to roof, 15 or 20 meters; at others, it is divided by intercalated shale, sandstone or conglomerate,. up to several meters thick. This great mass of coal is at 500 to 800 meters above the base of the formation, near which are some irregular deposits of anthracite.

The conditions are similar in les Ferriéres, where the principal deposit, apparently contemporaneous with that of les Pegauds, has a curved outcrop and thins to disappearance at both extremities. The coal has less volatile than that in the other sub-basin.

Fine sandstone prevails in les Pegauds, but coarse material is not wanting. One remarkable mass, marking the course of a violent flood, was formed shortly before the beginning of the Grande Couche. It is coarsest midway, where some blocks are of enormous size, but it shades away on each side into fine sand. Another coarse deposit is intercalated in the Grande Couche, but it is only a few hundred meters long and passes into the coal at each extremity of its outcrop. Fragments of Coal Measures rocks are found in all parts of the section. Those of shale, by their form, suggest to Fayol that they were plastic when enclosed. The pebbles of coal usually resemble in composition the coal nearest to them; those of the basal portion are anthracitic; those of les Ferriéres are maigre but in deposits overlying the Grande Couche the pebbles are usually of coal with long flame, though rare specimens of anthracite occur.

The coal occurs in films and in seams. *Calamites* are rare in the roof of Grande Couche but *Calamodendron* abounds. The flora is the same throughout and continues into the Permian; but there is distinct localization of forms. *Lepidodendron* and *Stigmaria* are present in the southwestern portion but are wanting in the eastern. *Knorria, Lepidophloios, Lepidostrobus* are in the roof at western localities. Fish and insect remains are abundant in some portions. Renault studied many specimens of trunks and branches enclosed in the fine sands. Their coal is derived from decomposition of vegetable material; there is no evidence of enrichment by infiltration, as the enclosing sand contains neither coal nor bitumen. At times a

branch is found, which has been changed in one portion into clean, compact coal, while in the other it has become fusain.

Aside from shaly seams, the coal usually has from 6 to 8 per cent. of ash, yields 60 to 62 per cent. of bright coke and gives off gas burning with brilliant flame. Analyses by Regnault and by Carnot give the ultimate composition:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
I........	82.92	5.30	11.78
II........	83.21	5.57	11.22

Cannel is of common occurrence in the Grande Couche as thin streaks or as lenses, which sometimes extend hundreds of meters; it yields a brilliant gas and has from 33 to 58 per cent. of carbon. Fayol seems to be inclined to believe that difference in character of coal may be related in some way to the ash-content; ordinary coal has 5 to 10, cannel, 7 to 12 and boghead 25 to 50 per cent. of ash.

Trunks, branches, etc., are in rocks of all kinds; are usually prostrate, but some are inclined, others erect. There are few in conglomerates, ten times as many in sandstones, 200 times as many in shales and 1,000 times as many in coal. Erect stems are rare in coal and shale, proportionately they are most numerous in the coarser rocks. At one locality, Fayol found a fern stem inverted. Attached branches are rare but many stems retain their roots. Still, the most of them have neither roots nor branches; but there are stumps retaining roots spread out on the underlying deposit, which they do not penetrate. One such stump, with diameter of one meter, showed 15 *Stigmariæ* radiating from it and enclosing a space of about 400 square feet. These *Stigmariæ* are arranged regularly and are flattened. Stems of trees, numerous in the coal, are compressed, the interior portions having disappeared, the rind only remaining, converted into coal.

The roof is of ordinary carbonaceous or bituminous shale, passing upward gradually into sandstone. Commonly it is rich in plant remains. The floor is usually carbonaceous shale, but occasionally sandstone, and the passage to the coal is gradual. There are many cases of contemporaneous erosion. One in the Tranchée de Forêt

removed the roof and much of the coal along a line of 80 meters on the outcrop. About 40 meters of Permian beds remain; the succession is discordant.

Fayol's conception is that the coals were deposited as transported vegetable matter on the sides of the submerged deltas in the lake or in the bays separating them. A remarkable feature observed in the Tranchée de l'Esperance is regarded by him as due to a slide on the watersoaked surface of the delta. The folding is very distinct in a close synclinal where the rocks are different in color from those of the wrinkled Coal Measures beds on one side, where exposures are complete. As the coal has been mined in vast open works, the conditions are well shown in two adjacent excavations. The locality was visited by Stevenson[84] in 1909, who explained the matter very differently. He regarded the light colored rocks of the synclinal as a deposit filling a channel-way eroded after the coal had been consolidated. The distortion of the strata was caused by eruption of a great mass of dioritine, the lateral thrust folding the rocks, crushing the coal into polished lenses and causing shale beds between sandstones to become wrinkled. This thrust produced a horizontal fault under the severely flexed rocks, which is well-exposed in the Tranchées Longeroux and de l'Esperance. The disturbance becomes insignificant east from the former tranchée as distance from the dioritine increases.

Autun.—Permian in the little basin of Autun contains the boghead, which, according to the studies by Bertrand and Renault,[85] consists chiefly of algæ enclosed in a "fundamental matter." It closely resembles the Kerosene Shale of New South Wales.

The deposit is thin and in limited space; it extends north from Autun for about 7 kilometers and is from 150 to 450 meters wide. It disappears away from a certain depth and is represented on the borders only by small lentils, irregularly scattered. The principal lens is from 23 to 25 centimeters thick, but exploitation is profitable as the yield of oil on distillation is very large. The boghead is

[84] J. J. Stevenson, "The Coal Basin of Commentry in Central France," *Ann. N. Y. Acad. Sciences,* Vol. XIX., 1910, p. 198.

[85] C.-Eg. Bertrand et B. Renault, "Pila bibractensis et le boghead d'Autun," *Bull. Soc. d'Hist. Nat. d'Autun,* t. 15, 1892, sep., pp. 1–93.

homogeneous, elastic, broken with difficulty, is deep brown and has a resinous luster. The lamination, due to colonies of algæ, is often minute and recognizable only on close examination. The "fundamental matter" contains infiltrations, pyrite, calcite and thelotite, the last being an enriching material, coloring the algæ blood-red. Analyses of specimens from two localities show

	Volatile.	Ash.
Margenne	65.6	34.4
Thelots	73.75	26.25

but these were selected specimens; ordinarily the ash varies from 35 to 48 per cent. The organic matter consists of carbon, 80; hydrogen, 10; oxygen and nitrogen, 10; the ash from the two localities named contains

	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Margenne	67.7	10.8	15.7
Thelots	60.5	14.4	17.4

The algæ, *Pila bibractensis,* B. and R., belong to the gelatinous group and are fresh-water forms like the fleurs d'eau. No spores, sporangia, sexual organs or embryos have been discovered. These algæ, at times, compose 75.5 per cent. of the whole mass. The "fundamental matter" contains remains of organisms, *Pila,* fish and grains of pollen; the last being in great abundance, 25,000 to 80,000 in a cubic centimeter, indicating showers of pollen. Besides these, are fragments of wood and leaves; but neither cyprids nor diatoms were observed.

The deposit is a lens, formed as cannel in a pond as is the organic mud, which so often is foundation for a peat deposit. The reasons for regarding the thelotite, pyrite and calcite as infiltrates are not very clear. Certainly the source of the thelotite was not ascertained. If it came from the enclosing bituminous shale, it can hardly be regarded as extraneous. Bertrand and Renault think that the boghead was formed in quiet water with little or no current and they regard the fundamental matter as ulmin which was held in solution. It is quite possible that the lime, present in considerable proportion, would suffice to precipitate the ulmin, but in that case it

is difficult to conceive how the supply could be maintained in quiet water. It must be remembered that the proportion of dissolved ulmin is very small: Smith[86] ascertained that very brown water contains only 4 grains to the gallon, and that if the quantity be 6 grains, the color is intensely dark.

It should be noted here that the conclusions reached by Bertrand and Renault have been controverted emphatically by Jeffrey and by Thiessen,[87] who employed improved methods of preparing the material. Jeffrey examined the Autun and other Bogheads and found no algæ but abundance of spores. Thiessen's results were very similar.

Bretagne.—Several small basins have escaped erosion in the area of the lower Loire Riven within Brittany. A general description of them was published by Barrois about 25 years ago, but his work is not now within the writer's reach. The only available notes are by Rolland,[88] presented many years since. These coals, almost anthracite, are regarded now as belonging to the Culm. The deposits described by Rolland are said to extend from Doué in Maine-et-Loire to Nort in Loire-Inférieure, about 40 leagues. He divides the section into eight systems, each with a conglomerate at base, the intervening rocks being sandstones and blackish shales. The first five systems, in each case, contain only thin streaks of coal, but the sixth, Goismard, has two seams, Petit and Grand Goismard, which at times unite and are mined. The upper, Petit, averaging about 50 centimeters, yields a hard lump coal and has as its roof a sandstone, pierre carrée, almost 70 meters thick. Its faux-toit is fine-grained sand, without cement and about one meter thick; it passes downward into a loose material, termed "tourte" by the miners and consisting mostly of decomposed feldspar. The mur of this seam, roof of the Grand seam, is shaly sandstone, 6 to 8 meters thick at the outcrop; at 100 meters down the dip, it is 3 and at 200 it is only 1 meter. In the deepest portion of the works, the seams have

[86] R. Angus Smith, *Manch. Lit. Phil. Soc.*, III., Vol. IV., 1871, pp. 50, 63.

[87] E. C. Jeffrey, "On the Nature of Some Supposed Algal Coals," *Proc. Amer. Acad. Sci.*, Vol. XLVI., 1910, pp. 273–390; R. Thiessen, "Plant Remains Composing Coal," *Science*, N. S., Vol. XXXIII., 1911, pp. 537–552.

[88] M. Rolland, "Notice sur le terrain anthraxifére des bords de la Loire," etc., *Bull. Soc. Geol. France*, t. XII., p. 463.

united and at a short distance beyond the union they disappear. The lower seam, 60 centimeters thick, yields a friable coal. Its mur is a tender shale, which breaks down into a whitish clay. The seventh system has three non-persistent seams and the eighth has but one; these are all thin.

Some sandstones in the fourth have many impressions of *Calamites* and the conglomerate at base contains many large, flattened fragments of stems. Those of the fifth have great abundance of *Calamites,* as well as of trunks of "palms," which are vertical to the stratification and are replaced with sandstone. Occasionally the shales in this system as well as those associated with coal in the eighth, contain impressions of leaves.

The coal is maigre with not more than 13 per cent. of volatile.

Spain.

Barrois[89] devotes 82 pages of his work on the northwestern part of Spain to the Carboniferous of the Asturias. He recognizes three assises: *Assise de Leña,* consisting of sandstones, conglomerate, shales, marine limestones and thin layers of coals; this he regards as equivalent to the Culm of Lower Carboniferous. *Assise de Sama,* equivalent to the terrain houiller moyen of Nord, France, as determined by Grand'Eury and Zeiller after study of the plants. The rocks are sandstones, some persistent conglomerates, rare limestones and numerous seams of coal. *Assise de Tineo,* equivalent to the terrain houiller supérieur of France, composed of shales, sandstones, some conglomerates with pebbles of Coal Measures rocks, and a large number of coal seams. There are no marine limestones. This is not conformable to the preceding deposits and in some areas it rests on the older formations.

Whether or not any representative of Permian exists in the region is uncertain. An earlier student was inclined to assign certain deposits to it, but Barrois thinks that, most probably, they belong to the Lower Carboniferous. The region has been subjected to violent disturbance, faults and overturned anticlines are numerous, so

[89] C. Barrois, "Recherches sur les terrains anciens des Asturies et de la Galice," *Mem. Soc. Geol. Nord, Lille,* 1882, t. 2, No. 1. Citations are from pages 519–600.

that detailed study is not possible in a considerable part of the area. The Coal Measures have an area of about 540 square kilometers in the Asturias and the principal basin is the Central, or Sama de Longres, containing not less than one third of the whole coal area; other basins are smaller, but in some cases are economically important.

The Assise de Leña receives its name from Pola de Leña, north from the Cantabrian Mountains, where the succession is well shown. It is exposed by an anticline in the Central basin, where its character is distinct. Near the montée de Cardeo in that basin, is a conglomerate belonging to this assise, which has aroused much discussion. It consists of large quartz pebbles, grayish white, which are marked in such manner that each observer has felt compelled to offer some explanation; some have regarded the phenomenon as due to chemical action, others think it due to pressure, to heat, etc. Barrois would explain it as due to wind agency. The sandblast produced by winds has had marked effect on quaternary pebbles in the Rhone Valley. Similar blasts could have polished or striated the pebbles of this conglomerate as they lay exposed on a beach. The coal seams of this assise are without economic value.

The Assise de Sama or lower division of the terrain houiller riche of former observers, is the important group of deposits in the Central basin. Coal seams are shown in one section associated with shales and sandstones containing impressions of *Calamites* and *Stigmaria* with nodules of clay ironstone; the coals rest on soft sandstone or shale filled with *Stigmaria*. Near Padrun is a conglomerate containing pebbles of coal, 4 to 5 centimeters in diameter. On Rio Caudal there appear to be about 30 seams of coal, arranged in groups which are separated by barren intervals. The mur usually is a compact shale crowded with *Stigmaria* and fragments of plants, but the toit has abundant beautiful impressions. A faux- toit, 10 to 15 centimeters thick, consisting of shale and coal, often covers the coal and at times is pulverulent. Barrois determined that the number of coal seams reported by earlier observers is far too great and that those who reported 72 to 80 seams failed to recognize several folds; he intimates that most probably the number is too great by at least one half. Throughout this basin, seams show much

variation in thickness, some, at times, thinning away to disappearance. One seam attains 3 meters; in one case coal only 30 centimeters thick is mined. Coals of the same age are in the small Santo-Firme basin, where the formation, resting on the Devonian, is about 500 meters thick and contains 10 coal seams. It underlies post-Carboniferous rocks. The coals show the usual tendency to vary in thickness, sometimes thinning away only to reappear within a short distance. A marine shale, rich in fossils, is roof of a coal seam in upper part of this assise.

The Assise de Tineo is confined to some small basins in the western and to two in the northern part of the old kingdom. In Tineo basin these rocks rest on the Cambrian. In Arnao and Ferrones they rest on Devonian and, because of faults, appear to be intercalated in rocks of that age. The basins of Ferrones has but one coal seam and the overlying Devonian contains fine fossils.

The province of Oviedo had 210 mines in 1869. Studies by de Aspiroz and by Paillette proved that the composition of the coal is not the same in different basins and that it varies even in the same assise. The most of the coal is bituminous but a maigre, anthracitic coal is obtained in Viñon and Calunga basins; this, of no value, may belong to the Assise de Leña. Volatile in the Central basin, belonging to the Assise de Sama, is 30 to 45 per cent. and the ash is from .04 to 3 per cent. But these are only of selected specimens. Coals from the small northern basins have theoretical interest. These give, according to analyses by Paillette:

	Volatile.	Ash.	Fixed Carbon.
Arnao	39	20	40
	49	7	42
Ferrones	45	12	42
	47	2	49
Santo Firme	38	5	55
	46	8	44

The Santo Firme coal belongs to Assise de Sama, that from Arnao and Ferrones, to Assise de Tineo. The difference in volatile might be attributed to the age of the coals, Santo Firme, the older, having less volatile; but Barrois thinks that another explanation, more satisfactory, may be found in the relation of composition to strati-

graphical disturbance. The Sama seams crop at many places where faulting and folding are marked, but in Arnao and Ferrones the disturbance is far greater; the section has been overthrust and the Carboniferous underlies Devonian. The coals which are richest in volatile are from areas which have suffered most severely from pressure. He notes, as bearing on the matter, that Gosselet had shown for the Nord area in France that the northern part of that region had suffered very little from disturbance while, in the southern portion, disturbance had been violent, there being at times complete inversion of the section. Yet coals are maigre in the northwest portion, whereas in the southwest, locality of greatest disturbance, one finds the fattest coals.

Great Britain.

The boundary between Permian and the Coal Measures is not always distinct in England. The unconformity is often small and it is difficult to determine a plane of separation, as rocks of the Upper Coal Measures closely resemble the type, which at one time was thought to be characteristic of the later period. But in considerable areas, the case is clear, for Permian rests on upturned, eroded Coal Measures. There appears to be good reason for believing that the system of flexures, traceable from England across France and Belgium into Prussia, originated toward end of Coal Measures deposition.

Permian deposits of Great Britain are equivalent to the Zechstein and Rothliegende of the Continent, as Murchison[90] held. They are absent from southern England and Wales and Hull believes that that area was exposed to denudation during the Permian interval. The Zechstein (Magnesian Limestone) has escaped erosion in only petty areas but the Rothliegende, covering extensive spaces in several fields, is thoroughly well marked, consisting chiefly of red and purple marls and sandstones, with occasional conglomerates and sometimes, on top, a breccia, containing fragments of trap and Silurian rocks. In the South Staffordshire coal field, the thickness

[90] R. I. Murchison, "Siluria," p. 347; E. Hull, "Coal-Fields of Great Britain," 4th ed., 1881, p. 524.

is estimated by Jukes[91] at from 1,000 to 3,000 feet, but the lower portion is almost beyond doubt of Coal Measures age. In other fields it is much less. Coal rarely occurs; Jukes notes a local seam, 10 inches thick and resting on fireclay. Numerous casts of *Sigillaria* were obtained from red sandstones lower in the section.

The Carboniferous deposits have been grouped into:

Upper Carboniferous. Upper Coal Measures; Middle Coal Measures or Pennant Series; Lower Coal Measures or Ganister Series; Millstone Grit.

Lower Carboniferous. Yoredale Shales, equal in part to Pendleside; Carboniferous Limestone.

Classification of the Coal Measures is perplexing and field workers have employed designations in the local sense. Kidston has offered a grouping based on an elaborate study of the plants:

Radstockian Series; Staffordian Series; Westphalian Series; Lanarkian Series.

The first two are the Upper, the third is the Middle, while the fourth includes the Lower Coal Measures and the Millstone Grit.[92]

Happily, the matters involved in this study have, except in a few cases, little to do with questions of classification, so that, in preparation of synopses of reports, it is sufficient usually to accept the grouping employed by the authors.

The South Wales Coalfield.—This, in the southern portion of England and Wales, was restudied by A. Strahan, W. Gibson, R. H. Tiddeman and T. C. Cantrill.[92] It extends from Monmouthshire at the east to Pembrokeshire at the west. The Permian is not present but the Carboniferous, Upper and Lower, is well marked. The Coal Measures are readily divisible into Upper, Pennant or Middle, and Lower, which are now regarded as equivalent to those of other fields. The Millstone Grit is persistent and characteristic; it and the Coal Measures thicken greatly toward the east; but their total

[91] J. B. Jukes, "The South Staffordshire Coal-Field," 2d. Ed., 1859, pp. 12, 13.

[92] This classification was presented first in 1888, but the final statement with explanations is given in R. Kidston, *Trans. Roy. Soc. Edinb.*, Vol. I., 1914, pp. 74, 75.

[93] "The South Wales Coal-Field," Parts I.–X., Geol. Surv. Mem., 1899–1912.

thickness is much less than was estimated by the earlier survey. The Lower Carboniferous limestones and shales are without coal.

The Upper Coal Measures, consisting of shales and sandstones with mostly irregular coal seams, has at base a well-defined persistent coal, known as Mynyddislwyn, Llanwit I, Wernffraith and Swansea in different districts. A vertical section of 111 feet in the Blackwood Valley near Newport of Monmouthshire, shows six coals, 6 to 30 inches thick, but they are extremely irregular. The Mynyddislwyn is double and the parting varies in thickness; in one area, it varies from 2 to 24 feet; in another, from 6 inches to 15 feet, while in another the parting of 2 feet becomes 15 feet within a short distance. Crossbedded sandstone is not unusual in the eastern part of the field.

The middle division or Pennant Grit is for the most part a clayey somewhat feldspathic rock at the east, which thickens very rapidly toward the west, where it is broken by shales. No workable coals are known at the east but southwardly and westwardly several seams become workable, though as a rule the coal is of inferior quality. The Tillery Coal, known in portions of the field as the Brither, Rhondda 2, Ynysarwed and Garn Swilt, is at the base. This Grit has occasional bands of conglomerate, containing quartz pebbles and rounded fragments of ironstone, coal and Coal Measures rocks. In Glamorganshire, where shales are in upper part of the Pennant, there are three workable seams, while farther west some coals are important. A crossbedded sandstone is the roof of Rhondda 2; at others that roof is conglomerate with pebbles of ironstone and coal; this is common in western localities.

The Lower or Steam Coal Series consists very largely of shale at the east but sandstone increases toward the west. It contains the coals which have made the field so important. In the upper portion, below the Tillery Coal, there occurs a notable thickness of red shale, which is very characteristic along the eastern side. The rocks generally show much variation, thickening rapidly toward the west, where they become coarser.

The coal seams change much in structure as well as in quality, but some of them are so persistent as to be definite stratigraphical horizons. The best-marked seam is that known as the Rock, Black,

Ras-Las, Nine-feet, Bydylog in different parts of the field; its variations may be taken as typical. At most localities, it is double with a variable parting of clay, but there are definite partings, without inorganic deposit, separating benches, differing in the character of their coal. At some localities, it is troubled by "nips," the shale roof disappearing and the underclay becoming sandstone, while the coal thins away. In some districts there are considerable areas where the coal is so poor that it is not worth mining; yet, in most localities, it is a thick bed and yields excellent coal.

"Washouts" are by no means infrequent. The Ras-las is missing at one place in northern Monmouth. In the Ebbw Valley of the same county, a great washout was encountered, extending 1,200 yards and causing removal of a section, 116 yards thick, with three coals, Three-Quarters, Black and Yard. The Ras-las has been washed out for not less than a mile in the Sirhowy Valley; in the Bargoed-Taff Valley it has been rendered almost worthless at many places by wedge-shaped masses of shale, cutting down to or nearly to the base of the seam, but not below it. These resemble channels of rivulets, filled with mud before deposit of the overlying rocks. Local deposits of coal are not unusual. De la Beche[94] saw, near the village of Bagelly in southern Pembrokeshire, some irregular masses of stone coal. One, semi-oval, is 140 yards long, 40 wide and 10 deep; four others of similar type were observed. Such coals seem to characterize the Millstone Grit, since all are local. Cannel is not abundant; it may be on top or midway in a coal seam, but it is always in contact with the coal. A seam, one foot thick, was seen at one place, but it appears to be local.

Strahan[95] has emphasized the plasticity of shale when between more resistant rocks as shown at some places in the Neath Valley. There as well as in Cynon Valley near an overthrust fault, the Nine-feet coal has a layer of shale pressed in to close wrinkles; the coal has become schistose, weathering into plaquettes, with razor edges, slickensided and very brittle.

The lower shales and sandstones of the Lower Coal Series have

[94] H. T. de la Beche, "On Geology of Southern Pembrokeshire," *Trans. Geol. Soc.*, II., Vol. 2, 1829, p. 19.

[95] A. Strahan, Part IV., p. 16; Part V., p. 65.

yielded many trunks of trees, some of which are now in the Museum at Swansea. Many years ago, de la Beche and Logan[96] saw two erect stems near the head of Swansea Valley in Glamorgan; the shale underlying the sandstone was uncovered and found to contain abundance of vegetable remains, proving it to be a vegetable soil, but the statement does not indicate that roots were found attached to the stems. The trees were *Sigillaria;* vertical stems of this type occur frequently.

Coals in this field decrease in volatile content downwardly; the Upper and Pennant coals are gas, while those of the Lower Series are steam coals. But the variation is more marked in all seams as they are followed westward; gas coals become steam coals and the steam coals become anthracitic until at last in the western portion anthracite prevails. It should be noted here that the total thickness of measures in the anthracitic area is very much less than was estimated by the earlier surveyors. Strahan[97] has given an elaborate discussion of the conditions, which well deserves careful consideration.

The South Staffordshire Coalfield.[98]—This is chiefly in the southern part of Stafford but extends into the adjoining counties of Worcester, Shropshire, Warwick and Salop. The region has undergone great disturbance and correlation is hardly possible in some portions, but the relations are clear in the northern districts. The Lower Carboniferous and the Millstone Grit are not reached but the Permian and the Coal Measures are present. The boundary between these formations had not been determined at the time when Jukes wrote; they appear to pass gradually one into the other. No unconformity has been seen between Coal Measures and the deposits taken to be Permian. The latter according to Jukes are from 1,000 to 3,000 feet thick and are extremely variable. Observations by geologists in recent years make more than probable that the lower part of this Permian belongs to the Radstockian Series of Kidston.

The succession below Permian, according to Jukes, is: (1) The

96 H. T. de la Beche, "Geological Observer," Amer. ed., 1851, p. 482.

97 A. Strahan and W. Pollard, "The Coals of South Wales," etc., Mem. Geol. Survey, 1908, pp. 65 et seq.

98 J. B. Jukes, "The South Staffordshire Coal-Field," Mem. Geol. Survey, 2d ed., 1859.

Halesowen Sandstone Group; (2) The Red Coal Measures Clays; (3) The Coal Measures. The first and second are each about 300 feet thick; the Coal Measures have a minimum thickness at the south of about 400 feet and increase northwardly to possibly 1,300.

The Halesowen Sandstones and the Red Clays were thought for a long time to be Permian, but careful study by Ramsay, Hull and Jukes fixed their place finally in the Coal Measures. The Halesowen sandstones are olive-green, brownish to yellow sandstones with two thin coals. They rest on a mass of red, green and mottled clays containing a thin coal, occasionally 9 inches thick. The predominating color is red.

Six persistently important seams of coal are present in the Coal Measures along with a much larger number of thin or dirty seams, which are without value. Among the latter is the Herring Coal in upper part of the section; it is a local deposit, almost worthless as coal, but is of interest because it contains great numbers of fish spines, whence the name given by miners. The remarkable feature in this field is the tendency of coal seams to divide, shown most strikingly by the Thick Coal. This seam, with a roof of black shale, consists of 8 to 14 benches, resting directly on each other or separated by thin partings of clay or shale. Each bench has its own name and retains its character throughout the Thick Coal district. At 2 miles north from Dudley there are eleven benches, with about 36 feet of coal, and partings, in all, amounting to 3 feet; at 1 mile east from Dudley it has 28 feet of coal in 12 benches and less than 2 feet of partings. The Top Slipper and the White, in upper part of the seam, are the best house fuels, but next best are the Sawyer and Slipper in the lowest fourth. The best coking coals are from the Tow, below the top fourth, and the Benches at the bottom, both of which contain much mineral charcoal. These are the conditions near Dudley but changes appear quickly in exery direction. Northward, the Roof and Top Slipper pass off as a separate seam, the Flying Reed, which, at Cosely, is 84 feet above the Thick, and at Billston still farther north, the interval is 208 feet. The Flying Reed thins away not far from Billston. The Thick and the Brooch Coals are almost parallel in this area, the Flying Reed diagonaling between them. The other benches of the Thick show a similar

tendency to separate and eventually that seam appears to be represented by 9 seams in a vertical section of about 400 feet. The same features were observed in other seams, though to less extent. The Heathen Coal, at about 20 feet below the Thick in the Dudley area, is at times 43 feet above the Lower Heathen, though these are united in some districts. The New Mine Coal divides near Bentley into two seams, separated by 33 feet of sandstone and shale; and the Bottom Coal parting, ordinarily 1 foot, becomes 50 feet.

The coal seams show as elsewhere variations in thickness and in quality, but these are most marked where the area is near the original limit of the seam. The coal is bituminous throughout. There is little cannel.

Much red and mottled clay and clunch is present above and below the Thick Coal; similar rock occurs near Brierley Hill in the lowest portion of the Coal Measures. Crossbedded sandstone is not wanting and there are many beds of ironstone.

"Rock faults" and "swells" occur only too frequently. At the Old Baremoor colliery, the measures are regular, but at the New Baremoor, the upper portion of the Thick Coal, 9 feet thick, rests on 42 feet of sandy shale, below which are 44 feet of "rock binds" to the Heathen Coal, which at times is replaced by the rock. The lower part of the Thick Coal fringes out on both sides into the rock mass. This is 282 yards wide and it has been followed northward for 400 yards without reaching the end. The bottom of this rock descends toward the north, cutting the lower bands of the coal and the underlying rocks to the Upper Heathen Coal. Thin wedges of sandstone extend into the coal. "Swells" are risings of the floor, often one or two hundred yards long. Jukes thinks that they may have been merely heaps of sand or mud. An important "swell" in the Baremoor colliery showed that partings in the coal thickened appreciably as they approached the swell, with which they united.

There is complete conformity throughout the Coal Measures, Ironstone beds in many cases contain numerous marine fossils.

The North Staffordshire Coalfield, surveyed by Gibson,[98] has the sequence complete. The Upper Coal Measures or the Red and Grey

[99] W. Gibson, "The Geology of Coal and Coal-Mining," London, 1908, pp. 175–182.

Series of Gibson, consists of the Keele, Newcastle and Etruria Marl groups. The Keele is equivalent to the lower part of the Permian of South Staffordshire while the other groups answer to the Halesowen sandstones and Red Coal Measures Clays of that field. The Keele is the Radstockian of Kidston and the other groups form his Staffordian. The total thickness is 2,200 feet. The Grey Series is grouped into Black Band, Middle and Lower Coal Measures with thickness of about 5,600 feet. The Millstone Grit and the Lower Carboniferous, which are reached at the northern side of the field, are without economic interest.

The Keele consists of red sandstones and marls, which are easily distinguished from the Etruria Clays and from those which occur at various horizons in the Middle and Lower Coal Measures. The Newcastle group, largely sandstone, contains four thin coals, but Keele and Etruria are barren.

The Black Band, only 400 feet thick, has three or more coals associated with the valuable deposits of black band, but the important seams are in the Middle Coal Measures, there being 13 of workable thickness and yielding good coal. Most of them average almost 6 feet, seldom reaching 8 feet. Several workable seams are in the Lower Measures. In greatest part, the coals are steam or house fuels, but as they approach the anticline or western boundary of the field, they often change into coking and gas coal.

Marine fossils have been obtained from 9 horizons, the bands being distributed in the column from base of the Coal Measures up to within 700 feet of Black Band. The Keele group has 3 horizons, from which *Spirorbis* has been obtained; these horizons have been recognized in deposits overlying the Halesowen Sandstones in South Staffordshire.

The Lancashire Coalfield.—This is one of the most important in England. Bolton[100] gave a summary description of it in 1897, utilizing results of studies by himself and earlier observers. The Permian deposits in the Pendle range rest on upturned and denuded edges of Coal Measures and pass beyond them to the Millstone Grit.

The Upper Coal Measures, best shown in the Manchester area,

[100] H. Bolton, "The Lancashire Coal Field," *Trans. N. Y. Acad. Sci.*, Vol. XVI., 1897, pp. 227–239.

not far from 2,000 feet thick, consists of reddish shales and sandstones with some thin limestones. At Bradford colliery, near Ardwick, 7 coal seams, 10 inches to 3 feet 6 inches, were found in a section of about 700 feet. These have been exhausted. The Middle Coal Measures, not far from 3,000 feet thick, contains about 10 workable seams, which are practically persistent, though some of them vary greatly. The coal is apt to be inferior when the thickness exceeds 4 feet, as it is injured by increasing number of thin dirt-bands. The Wigan cannel has abundance of fish remains and *Stigmaria*. The sedimentary deposits are extremely irregular, hundreds of feet of shale at one place being represented by a few feet of sandstone at another. A notable mass of red sandstone, with plant remains and 146 feet thick, rests on the Blenfire Coal at Glodwick colliery in the extreme eastern part of the field. The Lower Coal Measures, about 1,200 feet thick, has numerous seams but, for the most part, they are thin. The Bassey or Salts Mine Coal has a maximum of 23 feet, but its coal is inferior and little used. The Ganister, where thickest, has two benches, Upper Foot and Ganister; when united, the bed has thickness of 8 feet, but in a large area these are separated, the interval reaching 30 feet, and the benches become 2 feet 6 inches and 8 inches. The Millstone Grit, about 5,000 feet thick, has a thin coal seam in the upper division or Rough Rock, and another lower down. Casts of *Lepidodendron, Sigillaria* and *Calamites* are numerous in several sandstones and the shales often yield marine fossils.

Hull's[101] studies have supplied most of the information available for this field. In one of his memoirs, he has described in detail the Wigan area, central in the field. The Permian, chiefly red sandstone, is not found anywhere in contact with the Coal Measures, but the unconformity is beyond doubt, as Upper Coal Measures are not present at some localities where undoubted Permian occurs. It contains no coal.

The Upper Coal Measures, about 1,500 feet thick, red and gray sandstones and marls with bands of limestone, has no workable coals. The Middle Coal Measures, about 2,500 feet thick, and con-

[101] E. Hull, "The Geology of the Country Around Wigan," Mem. Geol. Survey, 2d Ed., 1862, pp. 1–39.

taining all of the thick coals, consists of reddish, gray, yellow sandstones and shales with coals and fireclays. The last are rich in *Stigmaria*. The Coal seams vary much in quality as well as in thickness. In the western part of the area, one portion of the section contains only unimportant coals but in the eastern part, near Wigan, it has, beside some thin streaks, the Haigh Yard, an excellent coking coal, as well as the King and the Cannel. The King has a maximum of 7 feet near Haigh, but thence as a center it thins away toward north, west and south. The Cannel has chief importance near Wigan, where it is 3 feet thick; but it is a lens, thinning away in all directions and it is represented by ordinary coal toward the eastern border. This and the King coal are almost in contact in a considerable area, but northwardly they separate until the interval becomes 60 feet. A cannel, 2 feet 3 inches, is in the St. Helen's section at several hundred feet above the place of that at Wigan, but it disappears northwardly and is represented by black shale at Wigan.

The Lower Coal Measures, about 1,800 feet thick, consists of micaceous flagstones, shales with thin coals. The fourth seam is the Ganister resting on a silicious underclay; the third is the Bullion Coal in whose roof are the "bullions," nodules of argillaceous limestone with *Goniatitis*. Marine fossils are found in the black roof shales. The Millstone Grit, coarse grits, flagstones and shales, has only two or three thin coals.

The sandstones of the Coal Measures and Millstone Grit are often reddish. Those of the Grit are in great part crossbedded, while those of the Coal Measures are described as "generally crossbedded, micaceous, ripple-marked and exhibit sun-cracks, perforations and tracks of annelides and perhaps of mollusks." The roof of the fifth coal of the Lower Coal Measures has vertical *Sigillaria*. The Ince 4-feet coal, near top of Middle Coal Measures, has thousands of vertical stems in its roof throughout the Wigan district. *Anthracosia* and *Anthracopteria* are at several horizons in the Middle Coal Measures and marine fossils are abundant in the Lower Measures. The Wigan cannel contains *Megalichthys, Holoptychius, Ctenoptychius* and *Diplopterus*.

No "washout" is noted by Hull or Bolton.

The Yorkshire Coalfield was described elaborately by Green[102] and his associates. It contains the whole column from Permian to the upper part of the Lower Carboniferous. The succession is: Permian, represented by the Magnesian Limestone, the Zechstein; Upper Coal Measures, perhaps 150 feet; Middle Coal Measures, about 3,500 feet; Lower Coal Measures, about 1,600 feet; Millstone Grit, perhaps 2,000 feet; Yoredale Shales; Carboniferous Limestone is not reached.

Permian and Upper Coal Measures deposits remain at very few localities and for the most part the boundary is obscure, for the relations of the lower beds are in dispute. The Magnesian Limestone rests unconformably upon the rocks in question. Near Pontyfract is a great sandstone, averaging not less than 75 feet, resting on about 40 feet of purple shale and yellow sandstone. It seems to be conformable to the underlying beds but is distinctly unconformable to the overlying Magnesian Limestone. This rock was referred by Smith and by Sedgwick to the base of the Permian, their conclusion being due in great measure to the red color, but Green asserts that this cannot be taken as criterion, for red color characterizes many deposits, which belong undeniably to the Coal Measures. Near Conisborough, the Pontefract is wanting and the Magnesian Limestone overlies 34 feet of very red beds. These rest conformably upon the underlying beds and contain Coal Measures types of *Neuropteris, Sphenopteris* and *Stigmaria*. The Red Rock of Rotherham, a great mass of sandstone and shale, occupies a trough eroded in the Middle Coal Measures. Its age is in dispute and Green declines to commit himself to either interpretation. The mass is certainly unconformable to the Coal Measures but a distinct exposure at one locality shows it distinctly unconformable to the undoubted Permian beds above.[103]

Coal seams are the most nearly constant deposits, because formed in swamps; but swamps must end somewhere; at their margins coal becomes impure, is split by increasing number of clay or sand layers until at length it is replaced with sandstone or shale. Evidence is

102 A. H. Green, R. Russell and others, "The Geology of the Yorkshire Coal-Fields," Mem. Geol. Survey, 1878, pp. xiii and 823.

103 Green and Russell, pp. 481–486.

ample, showing that there were many contemporaneous swamps, separated by low divides; their coals are at the same horizons but conditions must have differed locally, for the coal is not the same in all. The existence of such separated areas is distinct at many horizons. The Ganister Coal is present in the southern part of the field but is wanting at the north. The Better Bed is very irregular at the south but is important at the north. The Silkstone Coal is very good near Cawthorne, but thence for a long distance it is badly broken; when the regular seam is reached again at this horizon, it is of different character. More striking is the occurrence of petty isolated swamps, occupying depressions on surface of great sand heaps. Many seams are important only within very limited areas and sometimes a whole group of coals disappears.[104]

The composition of the coal in the several benches of a seam is rarely the same and occasionally the difference is notable. One bench may yield semi-anthracite and another bituminous coal; that from one bench may be caking and that from another may be non-caking. Variations of this type are so numerous as to be commonplace.[105] Cannel, the "stone coal" or miners or, if it contain high ash, "johnnies," is not rare. It has no definite position; it may be at the top or bottom or in the middle of a seam; a whole seam may consist of cannel; but in every case it is lenticular.

The coal varies in thickness as well as in quality. A great many seams are worthless because of ash or sulphur; even in any seam one bench may be clean, another dirty; the coal at one mine may be excellent, at another near by, it may be unfit for use. Faux-mur and faux-toit are characteristic, inferior coal at top or bottom or both being reported from many localities. The faux-mur of the Silkstone Coal is crowded with *Stigmaria* at one mine. The roof of the Ganister Coal has marine fossils in the shale as well as in the "bullions."[106] Marine fossils are in the roofs of several coals in the Millstone Grit. These occur rarely in the Middle Coal Measures and the black shales containing them are thin.[107]

[104] Op. cit., pp. 20, 21, 128, 242, 294, 300, 400, 410, 441 and many others.

[105] Op. cit., pp. 270, 271, 281, 382 and others.

[106] These have been studied by M. C. Stopes and D. M. S. Watson, *Phil. Trans. Roy. Soc.*, Ser. B, Vol. 200, 1908, pp. 167–208.

[107] Green and Russell, op. cit., 40, 63, 70, 71, 110, 230, etc.

Coal seams are rarely single, usually are divided into benches by partings of clay or sandstone which may vary greatly in thickness, though ordinarily the variations are within narrow limits. At times they are great enough to render the identification of seams more than perplexing. The Beeston Coal has its two benches in contact at Beeston, but within a short distance they are separated by an interval of 30 feet. Three seams of the Brown Metals Group show notable changes in relative positions; the interval between Number 1 and Number 2 is 6 inches to 56 feet, and that from Number 2 to Number 3 is from 12 to 66 feet. Other illustrations are noted, but these suffice for illustration.[108]

Contemporaneous erosion is by no means unusual and at some localities its work was extensive. In this, one may see evidence of areal changes of level. Near Penistone, a tunnel has disclosed proof that the region was exposed to denudation for a time in the early part of the Middle Coal Measures. A hill of Coal Measure sandstone remained, against which shales and two coal seams abut, which were formed in the valley around the hill. The Handworth Sandstone, southeast from Sheffield, occupies a valley eroded in the underlying shales, but is conformable to the overlying measures. The great red sandstone of Rotherham is unconformable to the underlying measures, occupying a broad valley cut in them. Coal seams are troubled by "rock faults" of one sort or another. The Old Hards Coal is wanting in some collieries, having been replaced with a deposit containing pebbles and water worn bowlders. The Haigh Moor Coal, one of the most important seams, is injured so badly by rock filling the lines of old watercourses, that in one district it is practically worthless. The "faults" are from 8 to 70 feet across and have northwest-southeast direction. At times they are irregular, there being broad bands of sandstone, connected by narrow strips, which suggest a series of ponds.[109]

The Silkstone Coal (Middleton Main) is troubled by "splits," which re-unite. Kendall[110] examined one at Whitwood, where the

[108] Green and Russell, pp. 185–192, 289–298.

[109] Green and Russell, pp. 140, 281, 343–345, 397, 482, 689.

[110] P. F. Kendall, "On the splitting of Coal-Seams by Partings of Dirt," *Trans. Inst. Min. Eng.*, Vol. LIV., 1918, pp. 1–21.

Top Coal rises until it is 29 feet above the Bottom, thence descends until the two benches are again in contact: the same condition is shown in a second drift as well as in a neighboring colliery. This phenomenon is not rare; it has been observed in several seams within the Yorkshire field and geologists have reported its occurrence in other fields. Kendall thinks it is due to the filling of a channel with sand or clay, over which the swamp extended. The originally level top of the in-swept material is now convex while the originally convex bottom is flat. He conceives that during conversion of the peat into coal, the thin borders of the enclosed mass adjusted themselves to the changing thickness of the organic material until the upper surface became convex and the bottom flat. The existence of the gravel deposit has been proved along its west side for about 5 miles; the mass has been crossed by drifts at two places, which show a width of not less than 1,200 feet. Existence of such "splits" is known in the Silkstone Coal at many places, but these have not been connected by continuous workings. Kendall feels justified in asserting that the splits mark courses of ancient streams.

Limestone rarely occurs in the Yorkshire field, the prevailing rocks being sandstones, shales and underclays. The mollusks are mostly *Anthracosia* and *Anthracomya,* which are at many horizons, but undoubted marine forms are present in some thin black shales. The sandstones vary from conglomerate to fine-grained. The coarser rocks are irregularly bedded and in many cases they resemble huge heaps, thinning away in all directions. But there are such deposits, especially in the Millstone Grit, of vast extent and showing little variation in thickness or character. *Lepidodendron* and *Calamites* casts are not rare. Nearly all sandstones, coarse and fine alike, are false-bedded, often with marked current- or cross-bedding, and the finer sandstones frequently are ripple-marked. Shales may be sandy, blocky, passing into sandstones, or they may be argillaceous; sometimes they are black, passing occasionally into cannel. Underclay, known as Spavin or Seat Earth, is usually clay, always unstratified, never splits into layers, breaks into irregular blocks and always contains *Stigmaria,* with rootlets ramifying in every direction. "Many instances have been observed where fossilized trunks

of trees, still standing erect in the position in which they grew, and attached to their roots, rise out of an underclay." At times, the underclay underlies carbonaceous shale. Ganister is a very hard silicious earth, which is seat to numerous coals, especially in the Lower Coal Measures.[111]

Green mentions (p. 123) that an erect stem was seen rooted in a thin seam of coal and passing up into sandstone. Sorby[112] gave a brief note respecting erect stems, which he saw at Wadsley. In preparing the surface for a public building, the workmen exposed a considerable number of such stems. Sorby induced the authorities to construct sheds in order to preserve the finer specimens. The trees appeared to have grown in what is now a clay-like shale, then died and become decomposed to the top of the surrounding mud. They were hollow stumps and were filled with sand like that of the overlying sandstone. The stems are *Sigillaria* and the roots are *Stigmaria.* The largest and best specimen has diameter of 5 feet 2 inches and the top is not ragged. The roots, which bifurcate, are shown well to a distance of 6 feet from the stump. A prostrate stem lay alongside. Five stumps were exposed in a space of 40 or 50 yards.

In the *Northern field,* within Durham and Northumberland, coal seams make their appearance in the Lower Carboniferous and attain some economic importance. These become valuable in portions of Scotland, where they are the source of fuel supply for leading industries. It is unnecessary to dwell on the several fields, as, for the most part, the general conditions differ in the Coal Measures very little from those observed in England. It will suffice to make reference to but one field in Scotland.

The coalfield of the *Lothians* is in Edinburghshire and Linlithgowshire. It was studied long ago by Howell, Geikie and Young but more recently was examined in detail by Cadell.[113] The suc-

[111] Green and Russell, pp. 14, 17, 37, 58, 60, 97, 114, 140, 300, 323, 402, 437, 470, 496, 649, 666.

[112] H. C. Sorby, "On the Remains of a Fossil Forest in the Coal Measures at Wadsley, near Sheffield," *Quart. Jour. Geol. Soc.,* Vol. 31, 1875, p. 458.

[113] H. M. Cadell, "The Geology of the Oil Shalefield of the Lothians," *Trans. Edin. Geol. Soc.,* Vol. VIII., 1901, pp. 116 et seq.; Mem. Geol. Survey, 1906, 1910; "The Story of the Forth," Glasgow, 1913.

cession as determined by him is: Coal Measure, 1,000 feet, red sandstones above, coal seams in lower portion; Millstone Grit, 500 feet, without coal seams; Carboniferous Limestone, 2,000 feet, limestone, volcanic bed, coal seams, the Hurlet limestone at base; Calciferous Sandstone, divided into (1) Oil Shale Group, 4,000 feet, with 2 thin coals in upper part and oil shales in middle and lower parts; (2) Cement Stone group, without coal and resting on the Old Red Sandstone.

The great Carboniferous Limestone, thousands of feet thick in portions of England, is split up here into not more than a half dozen beds, each at most 50 feet thick, with sandstones, shales and coal seams in the intervals. There are many coals, almost 50, and at least 17 of them exceed 2 feet in thickness. One has maximum of 8 feet and another of almost 6 feet. These are thoroughly typical and rest on underclays with abundant *Stigmaria* in place. Ironstone, economically important, occurs at many horizons. At Bridgeness in the Bo'ness area, Cadell more than once explored an old forest exposed by workings on the Craw Coal. On one occasion, he counted 113 stumps, *Sigillaria,* distributed along 400 yards of roadway. They were arranged in clumps and were from two and one half inches to two and one half feet in diameter. The stems in great proportion were prostrate. Cadell conceives that they were broken off by a violent wind from the south, as most of them lie over toward the north. The vertical stumps were filled with ferruginous mud and the bark remained as coal. One of the sandstones is ripple-marked, has casts of fresh-water shells and flattened heaps of worm-castings.

Two thin coals, Two-feet and Houston, are about 1,000 feet below the Hurlet limestone; they are true coal seams but are very high in ash. The Houston, at one place, is 5 feet 9 inches in 4 benches, including a 2-inch cannel, directly under the top bench; at another, it is somewhat more than 11 feet and has a bench of oil shale. The coal is soft, but at its best is pyritous and dirty.

The notable feature of the group is the Oil Shales, which is easily recognized. It gives a brown streak, is tough, resists the weather and is not gritty. The thickness varies; at times a deposit disappears or passes into ordinary shale; at others, it may reach 15

feet, including partings of ordinary clay. It is finely laminated, but this feature is distinct usually only in "spent clay," that which has been treated. Thin streaks have been discovered in shales within the Carboniferous Limestone, but they are unimportant. Four important horizons are in the Calciferous Sandstone, the chief one being at 3,200 feet below the Limestone base. At some places, the shale has many impressions of fish; at others it is composed almost wholly of minute cyprids and crustaceans, so abundant that the shale resembles fine linseed cake. With these are fragments of ferns. The lagoon of deposit had an area of not less than 330 square miles. The best shale has fixed carbon, 5; volatile, 25; ash, 70 per cent. A yield of 30 gallons of oil per ton is that of good shale.

The Craigleith Sandstone, at base of the Calciferous, is well marked in the Edinburgh area, whence Witham obtained his tree, which, evidently, was a "snag." Brown[114] described this sandstone as made up of lenses, thinning out in all directions and dovetailing. Coaly laminations, derived from drifted material, are numerous. The water was shallow; sun-cracks, worm tracks, ripple-marks, rainprints and footprints of labyrinthodonts have been observed. Brown found in the quarry a large block of current-bedded sandstone containing several casts of *Lepidodendron*. The largest fragment, 3 feet long and 14 inches wide, was somewhat compressed and retained some of its bark, converted into coal. At one side in the interior was a thick layer of brown material, but the rest of the cavity was filled with sand. The brown substance contained numbers of the gasterpod, *Platyostomella*, and the "nests" were formed before the sand was deposited, for the laminæ of the latter curve around them. This gasteropod was probably an estuarine form. At another locality, it is associated with *Spirorbis pusillus*, which may indicate marine conditions. At the same time, the Craighill species has peculiarities, which lead Brown to suggest that, like *Hydrobia*, the genus may have had fresh-, brackish- and salt-water species. The question of adjustibility of molluscs to changing marine or fresh-water conditions is unimportant. They can and do

114 C. Brown, "On the occurrence of Gasteropods (*Platyostomella scotoburgalensis*) in a *Lepidodendron* from Craighill Quarry, Edinburgh," *Trans. Edinb. Geol. Soc.*, Vol. VII., 1897, pp. 244–251.

adjust themselves. De la Beche[115] states that *Voluta magnifica* lives high up in brackish water near Port Jackson, Australia, and that an *Arca* inhabits the fresh-water of Jumna River at 1,000 miles from the sea. G. B. Sowerby had informed him that an *Astarte* and a *Cardita* had been found in pools on the ice near Melville Island, and that a *Nucula* lives in the Ganges at Banda. An *Anodon* thrives in brackish water at the Commercial Docks of London, where it is associated with a *Mytilus* brought from the Danube. He cites McCulloch, whose experiments proved that many marine fish and crustaceans can become habituated even in fresh-water. Almost 80 years ago, J. W. Bailey discovered a strange commingling of fresh-water and marine types in the Hudson River near West Point, where one reaches practically the limit of brackish water.

South America.

Brazil.—Permo-Carboniferous rocks have been reported from several countries in South America and have been described in admirable memoirs; but such deposits are most important in Brazil, where, according to Branner,[116] "the Permian is, *par excellence,* the Brazilian series." They were recognized by Eschwege in 1832 and, since that time, they have been studied in the several states by many geologists, among them, F. de Castelnau, O. A. Derby, C. F. Hartt, Oliveira, P. W. Lund and M. A. R. Lisboa. For the most part, the examinations were reconnaissances, sufficing to prove extent of the deposits, but giving detailed information respecting few areas. Whether or not the Coal Measures are present remains to be determined. The Permo-Carboniferous has coal in the southernmost states.

Hartt[117] states that Perigot discovered the coalfields of southern Brazil in 1841. A detailed study of the deposits in Santa Catharina was made by U. Plant, whose report, made in 1869, was republished by Hartt. On the Rio Candiota, Plant found, in a section of 70

[115] H. T. de la Beche, "Researches in Theoretical Geology," Amer. ed., N. Y., 1837, pp. 224, 225.

[116] J. C. Branner, "Outlines of the Geology of Brazil," *Bull. Geol. Soc. Amer.,* Vol. 30, 1919, pp. 211.

[117] C. F. Hartt, "Geology and Physical Georgraphy of Brazil," Boston, 1870, pp. 519–531.

feet, 56 feet of coal in four seams, 3, 11, 17 and 25 feet. Coal from the 17-feet seam was tested by steamers on the Rio Grande with good results, though the ash is high. The coal is caking and yields from 6,700 to 8,198 cubic feet of gas with 5 to 5.8 candle-power.

Almost two score years later, White[118] examined the coal areas of Rio Grande do Sul, Santa Catharina, Paraná and São Paulo, the southern state of Brazil. His conclusions did not justify hopes based on reports by earlier observers. The deposits were laid down on an irregular surface of granite, which, at times, is within a few feet of the lowest coal, at others, separated from it by a considerable thickness of rock. The succession, near Minas in Santa Catharina, is: Santa Catharina System, composed of São Bento Series, 900 meters; Passa Dois Series, 228 meters; Tubarão Series, 280 meters. The São Bento Series, red sandstone and shales, is capped by a great thickness of eruptive rocks and is assigned to the Triassic. The Passa Dois Series, shales with thin limestone at top, is without coal and is referred by D. White to the Damuda series of India. The Rio Bonito sandstones and shales of the Tubarão Series, containing the coals, are 158 meters thick near Minas and have 5 coals; at one place in São Paulo, 170 meters and no coal; at one in Paraná, 270 meters and no coal; at one in Rio Grande do Sul, the group is but 57 meters with one thick and four thin coals; while at 18 kilometers farther south it is 145 meters with one thick and 13 thin coals. In the greater part of the region, the Rio Bonito consists chiefly of yellowish to grayish white feldspathic sandstones, which are poorly consolidated; in much of Rio Grande do Sul, however, shale predominates.

The coals were seen first in Santa Catharina, where, near Minas, 5 seams were examined, Treviso, Barro Branco, Irapuá, Ponte Alta and at bottom, Bonito; but at 60 miles northward, only one seam, probably Barro Branco, was seen. In the northern states, Paraná and São Paulo, the distribution of coal is indefinite; at best the seams are very thin and they are wanting in many districts. Even in Santa Catharina and Rio Grande do Sul, the seams are so irregular that they may be regarded as local, the only really persistent

[118] I. C. White, Commisão de Estudos de Carvão de Pedra do Brazil, Relatorio Final," Rio Janeiro, 1908, pp. 1–300.

horizon being the Barro Branco. Southwardly, the coal measures pass under cover not far south from Minas and come again to the surface near São Jeronymo in Rio Grande do Sul, where the Treviso is represented by shale, the Irapuá by shale and coal, but the Barro Branco or São Jeronymo is important. At Serro Partido near Rio Candiota, where Plant obtained his section, the section as measured by White is, thicknesses being given in meters, (1) shale, sandstone and concealed, 19.28; (2) coaly shale, 0.91; (3) shale with plants, 2.29; (4) coal and shale, 0.305; (5) clay, 1.52; (6) shales, dark and yellow, plants in latter, 1.04; (7) São Jeronymo Coal, 4.78, consisting of (*a*) slaty coal, with *Sigillaria* in roof, 1.22, (*b*) blue clay, 0.51, (*c*) carbonaceous shale, some coal, 1.22, (*d*) impure coal, 1.83; (8) clay and shale, 6.59; (9) interval in shaft, reported, 12.19; (10) Irapuá Coal, 0.20 to 0.36. It is evident that the earlier observer mistook dark shale for coal.

The one persistent coal horizon is the Barro Branco-São Jeronymo, but it varies greatly. It is usually triple in the Minas region, though more divided at times, the thickness varies from 0.93 to 2.20 meters, and the coal is described as "good" to "fairly good" and "slaty." In Rio Grande do Sul, it has, at one place, 2.68 thickness with a parting of clay, only 10 centimeters, but at other places this parting is from 3 to 5.30 meters. The other seams are traceable in the two southern states, but for the most part they are thin. The roof at most places is a leaf-bearing shale and the floor is clay or clay shale. One can hardly recognize faux-mur or faux-toit owing to character of the coal.

The coal is always high in ash and usually in sulphur. Analyses of that from the one important horizon show:

	Barro Branco.	São Jeronymo.
Moisture	1.01 to 1.21	3.43 to 6.05
Volatile	7.64 to 26.00	22.98 to 29.09
Fixed Carbon	35.34 to 54.63	37.52 to 44.20
Ash	24.88 to 28.38	23.04 to 31.17
Sulphur	1.58 to 11.42	0.60 to 12.96

The sulphur is present as pyrite and it, as well as a great part of the ash, can be removed by washing. Briquettes, made from washed coal, have from 8 to 14 per cent. of ash and 0.64 to 1.31 of

sulphur. The natural coal is inferior everywhere; evidently, the swamps, in which it was formed, were subject to frequent overflows of muddy water. There is no reason for believing that the sea invaded the region during the Permian.

D. White,[119] in the same volume, publishes an elaborate discussion of the plant remains and conditions. A shale in the Bonito Coal is crowded with megaspores, probably of *Sigillaria,* and a fine-grained flinty fireclay is filled with roots tentatively referred to *Vertebraria.* He found *Vertebraria* in the Barro Branco-São Jeronymo Coal as well as in shale near Minas and in roof of the Irapuá Coal. *Reinschia australis* Bert. and Ren., was observed in a fragment of boghead picked up on the coast. This material, he is convinced, is not from Brazil but was dropped from an Australian vessel carrying Kerosene Shale.

The roof of the Irapuá Coal contains *Glossopteris* and *Noeggerathopsis;* that of the São Jeronymo, at one locality, contains carbonized roots along with matted leaves of *Noeggerathopsis,* while, at another, it is an impure coal, whose dull layers are full of leaf and wood material in charcoal, and at a third, the dull layers consist largely of charcoal derived from *Lepidodendron, Sigillaria,* etc.

He finds Gondwana forms in the lowest portion of the coal measures. He is convinced that the Tubarão Series is practically equivalent to the Talchir-Kharharbari of India, Newcastle of New South Wales, Bowen of Queensland, etc. The Passa Dois Series is most probably equivalent to the Damuda Series.

119 D. White, The same, pp. 337–607.